FINAL PROJECT – ME141502

STRENGTH ANALYSIS OF VERTICAL AXIS TURBINE SHAFT FOR 5 KW CAPACITY ON OCEAN CURRENT POWER PLANT

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SURABAYA
2016

TUGAS AKHIR – ME141502

ANALISA KEKUATAN POROS TURBIN VERTIKAL UNTUK KAPASITAS 5 KW PADA PEMBANGKIT LISTRIK TENAGA ARUS LAUT (PLTAL)

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APPROVAL SHEET

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FINAL PROJECT

Submitted to Comply One of The Requirements
to Obtain a Bachelor Engineering Degree
on
Laboratory of Marine Manufacture and Design (MMD)
Bachelor Degree Program of Marine Engineering Department
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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Surabaya,
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STRENGTH ANALYSIS OF VERTICAL AXIS TURBINE SHAFT FOR 5 KW CAPACITY ON OCEAN CURRENT POWER PLANT

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ABSTRACT

The diversity of Indonesia's natural resources saves a lot of potential that can be developed. One of them is the potential of ocean current energy resources. Ocean current energy is one of renewable energy. In its utilization, it requires a turbine that will change the ocean current energy to become electric energy, named ocean current power plant. In its designing is needed a lot of requirement. Shaft is the main component that is important from a mechanical transmission system on ocean current power plant. The purpose of this research was to find out on appropriate shaft specification, then analyze the safety factor, strength ability of the material, and the deformation may be occurred on the shaft by using Finite Element Analysis Method, that implemented in Solid work simulation, a design tool. Calculation of force and load as well as the design of the shaft diameter is a very important factor in determining strength analysis. The results from this research showed the appropriate shaft is made by solid shaft with high tensile steel AISI 4140 material, where it has good ductility, good wear resistance, and corrosion resistance. Vertical axis turbine shaft arranged a series of three shafts having a length respectively 3,3 m, 2 m, and 2 m. The maximum stress is 144,061946 MPa and it is operated with factor of safety 4,5.

Keywords : ocean current, vertical axis turbine, shaft

ANALISA KEKUATAN POROS TURBIN VERTIKAL DENGAN KAPASITAS 5 KW PADA PEMBANGKIT LISTRIK TENAGA LISTRIK ARUS LAUT (PLTAL)

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ABSTRAK

Sumber daya alam Indonesia menyimpan banyak potensi yang bisa dikembangkan. Salah satunya adalah mengembangkan potensi sumber daya energi arus laut. Energi arus laut merupakan sumber daya terbarukan yang sangat potensial untuk dikonversikan menjadi energi listrik. Dalam pemanfaatannya, menggunakan turbin pada pembangkit listrik tenaga arus laut (PLTAL). Dalam merancang suatu pembangkit listrik tenaga arus laut dibutuhkan banyak perhitungan. Poros merupakan komponen utama yang penting dari sistem transmisi mekanik pada pembangkit listrik. Tujuan dari penelitian ini adalah untuk menentukan spesifikasi poros yang tepat, kemudian menganalisa faktor keamanan, kekuatan material, dan deformasi yang dapat terjadi pada poros dengan menggunakan *Finite Element Analysis Method*, yang diimplementasikan dalam simulasi *Solidwork*. Perhitungan gaya dan beban yang diterima poros serta perhitungan diameter poros merupakan faktor yang sangat penting dalam menentukan analisa kekuatan. Hasil dari penelitian ini menunjukkan poros yang tepat adalah berbahan pejal dengan material *High Tensile AISI 4140*, dimana ia memiliki daktilitas yang baik, ketahanan aus yang baik, dan ketahanan korosi. Poros turbin vertikal disusun dari tiga poros yang memiliki panjang masing-masing 3,3 m, 2 m, dan 2 m. Tegangan maksimum didapatkan 144,061946 MPa dengan faktor keamanan 4,5.

Kata kunci : energi arus laut, poros, turbin vertikal

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CHAPTER 1
INTRODUCTION

1.1. Background

Electricity is a basic requirement of society and supports in all aspect and for national development, including the improvement of living standards. Various attempts were made to overcome the electricity crisis by doing various research and development of alternative technologies and renewable energy. That is because the availability of electricity gradually always smaller than the growing need.

The diversity of Indonesia's natural resources saves a lot of potential that can be developed. One that can be developed is the potential of ocean current energy resources. An ocean current energy resource is potential to be converted into electrical energy. It utilizes marine kinetic energy by using the motion of ocean currents. Based on the results of the current velocity measurement and modeling that have been done in the Selat Toyapakeh of Nusa Penida are noted that in this location has practical potential energy of ocean currents. Therefore, it will be designed ocean current power plant in that area to develop the potential exists. The research and development of power plant technology of ocean currents also accordance with the Strategic Plan of Ministry of Energy and Mineral Resources 2010 – 2014, mentioned that one of the strategic objectives associated with the purpose of ensuring the supply of domestic energy and raw materials is increasing development of various sources of energy in order to diversify the energy, by encouraging the construction of power plants, in order to solve the problem of electric energy in the archipelago, so it can support Indonesia became an independent archipelago state and developed.

In the designing of ocean current power plants, exactly it needs many calculation and proper planning, one of them is designing the technology of mechanical transmission system. Certainly, it will need mathematical and technical calculations to determine and select the components and materials that are needed. The main component that is important from a mechanical transmission system is the shaft. Shaft is a rotating machine element which is used to transmit power. The power is delivered to the shaft by some tangential force and the resultant torque (or twisting moment) set up within the shaft permits the power to be transferred to various machines linked up to the shaft. In this case needs to design the transmission shaft to transmit power from vertical axis turbine wheel to gearbox and generator and then choose the material and analyze its structural strength include safety factor, stress, strain, deformation may be occurred.

In this final project, the analysis will do according to the data of rotating speed (rpm), torque, and power to be received by shaft, as well as analyzing the strength ability of the material while receiving some kind of stress in the process of loading received, strain, safety factor, deformation that may be occurred on the shaft using Finite Element Analysis Method that implemented in Solidwork simulation, a design tool.

1.2. Statement of Problems

According to the background of the study, this final project has the following statement of problems.

a) How the design calculation of vertical axis turbine shaft for a mechanical transmission system of ocean currents power plant.
b) How the strength analysis and its safety factor of vertical axis turbine shaft material while receiving some kind of stress on the loads process.

1.3. Scope of Problems

According to the research problem, this final project has the following scopes.

a) The design calculation and strength analysis of vertical axis turbine shaft are carried out according to existing source of rotating speed (rpm), torque, and power data of turbine.
b) Determine the dimension of the shaft (shaft specification), then analyze the safety factor, strength ability of the material, the deformation may be occurred on the shaft by using Finite Element Analysis Method, that implemented in Solidwork simulation, a design tool.
c) The analysis will only focused on the shaft of vertical axis turbine, as a transmission shaft and its support component for mechanical transmission system. The next concept of mechanical transmission system such as gearbox system and selecting generator will not taken into consideration.

1.4. Research Objectives

In accordance with the background of the study, this final project has these following objectives.

a) To design and to analyze the strength ability of vertical axis turbine shaft, as transmission shaft on ocean current power plant.
b) To find out an appropriate spesification of transmission shaft that capable for certain capacity on ocean current power plant.

1.5. Research Benefits

This final project will be able to give these following benefits.

a) Knowing the design and strength analysis of vertical axis turbine shaft, as transmission shaft of ocean current power plant.
b) Knowing the appropriate spesification of transmission shaft that capable for certain capacity on ocean current power plant.
c) The result of this final project is expected to be used as reference in designing of vertical axis turbine shaft for mechanical transmission system of ocean currents power plant in Selat Toyopakeh, Nusa Penida, and can work maximally.

CHAPTER 2
STUDY LITERATURE

2.1 Concept of Ocean Current Power Plant

In the life society, electricity is the energy has an important role. Almost everyday people always using electricity in the activities they perform. Electricity itself is obtained from conversion of kinetic energy into electrical energy. Energy Kinetic itself can be obtained from combustion sources energy derived from fossil fuels. However, availability of energy derived from fossil reduced. It makes the issue of innovation renewable energy.

Indonesia is the country with the potential for large sea. There are several forms of energy of the sea that can be used, such as ocean thermal, wave, wind, tidal, and ocean currents. Due to the global climate change and the energy crisis, the clean renewable ocean current energy with high energy density and good predictability has attracted an increasing attention [11].

The power plant was developed in a variety of energy exploitation, such as power of ocean currents (tidal current energy). Ocean current energy offers a vast and reliable energy source [7].

Ocean currents platform are offshore building convert ocean currents into electric energy with utilizing the rotation of the ocean current turbine. Ocean current turbine produce more energy than wind turbines, with the same dimensions of turbine and current velocity.

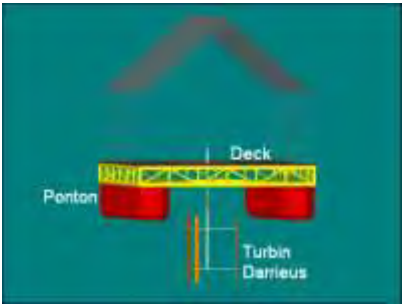


Figure 2.1 Ocean Current Platform [10]

2.1.1 TLP (Tension Light Platform)

There are several types of platforms for ocean current power plant. One of the types is TLP (Tension Light Platform). TLP is a platform with a simple type of box that has some properties :

1. Remotely operated units
2. Installation of topsides in one operation, reducing the offshore hook-ups
3. Suitable to develop a large deposit in deep waters or very deep waters
4. Has a lower movement region
5. Able was at a depth of up to 2000 meters

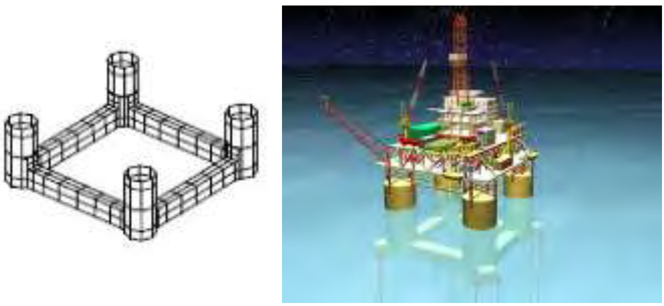


Figure 2.2 Tension Light Platform (TLP)

2.2 Turbine

Exploitation of ocean current energy use turbine device. A turbine is rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. In water turbines, ocean current will rotate the turbine and there is a generator that will convert the rotation of the turbine into electricity [11].

Based on the alignment of the rotor axis with respect to water flow, three generic classes could be formed horizontal axis (HAT), vertical axis (VAT), and cross flow turbines [3]. It is proven that the turbine model of the vertical axis (VAT) is a model turbine that appropriate in energy utilization of ocean current. Vertical axis turbine system has many advantages, especially on the side of simple design and lower cost, when compared with the wheelbase horizontal-type turbines . The types of vertical axis turbine classified into 6, they are SC-Darrieus (straight blade), H-Darrieus (straight blade), Darrieus (curved blade), Gorlov (helical blade), and Savonius (straight/sweked) [4].

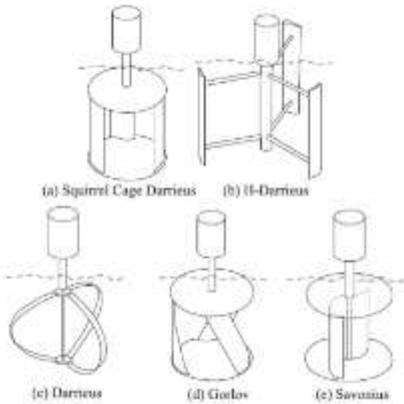


Figure 2.3 Vertical Axis Turbine [3]

2.3 Shaft

A shaft is a rotating machine element which is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque (or twisting moment) set up within the shaft permits the power to be transferred to various machines linked up to the shaft. [8].

Visualize the forces, torques, and bending moments that are created in the shaft during operation. In the process of transmitting power at a given rotational speed, the shaft is inherently subjected to a torsional moment, or *torque.* Thus, torsional shear stress is developed in the shaft. Also, a shaft usually cairies power-transmitting components, such as gears, belt sheaves, or chain sprockets, which exert forces on the shaft in the transverse direction (perpendicular to its axis). These transverse forces cause bending moments to be developed in the shaft, requiring analysis ofthe stress due to bending. In fact, most shafts must be analyzed for combined stress. [6]

2.3.1 Material Used for Shaft

In general, the material used for ordinary shafts is carbon steel of grades 40 C 8, 45 C 8, 50 C 4 and 50 C 12. The mechanical properties of these grades of carbon steel are given in the following table. When a shaft of high strength is required, then an alloy steel such as nickel, nickel-chromium or chrome-vanadium steel is used, such as ASME 1347, 3140, 4150, 5145, and so on. If the shaft necessary surface hardening, it is necessary used carburising steel material such as ASME 1020, 1117, 2315, 4320, 8620 or G4102, G4103, G4104. [9]

Table 2.1 Mechanical Properties of Steels Used for Shafts [8]

Indian Standard Designation	***Ultimate Tensile Strength, MPa***	***Yield Strength, MPa***
40 C 8	560 – 670	320
45 C 8	610 – 700	350
50 C 4	640 – 760	370
50 C 12	700 Min.	390

The material used for shafts should have the following properties :

6. It should have high strength.
7. It should have good machinability.
8. It should have low notch sensitivity factor.
9. It should have good heat treatment properties.
10. It should have high wear resistant properties. [8]

2.3.2 Manufacturing of Shaft

Shafts are generally manufactured by hot rolling and finished to size by cold drawing or turning and grinding. The cold rolled shafts are stronger than hot rolled shafts but with higher residual stresses. The residual stresses may cause distortion of the shaft when it is machined, especially when slots or keyways are cut. Shafts of larger diameter are usually forged and turned to size in a lathe. [8]

2.3.3 Types of Shaft

The following two types of shafts are important from the subject point of view :

1. ***Transmission shafts*.** These shafts transmit power between the source and the machines absorbing power. The counter shafts, line shafts, over head shafts and all factory shafts are transmission shafts. Since these shafts carry machine parts such as pulleys, gears etc., therefore they are subjected to bending in addition to twisting.
2. ***Machine shafts*.** These shafts form an integral part of the machine itself. The crank shaft is an example of machine shaft. [8]

2.3.4 Standard Sizes of Transmission Shaft

The standard sizes of transmission shafts are 25 mm to 60 mm with 5 mm steps; 60 mm to 110 mm with 10 mm steps; 110 mm to 140 mm with 15 mm steps; and 140 mm to 500 mm with 20 mm steps. The standard length of the shafts are 5 m, 6 m, and 7 m. [8]

2.3.5 Types of Stresses in Shaft

The following stresses are induced in the shafts :

1. Shear stresses due to the transmission of torque (i.e. due to torsional load).
2. Bending stresses (tensile or compressive) due to the forces acting upon machine elements like gears, pulleys etc. as well as due to the weight of the shaft itself.
3. Stresses due to combined torsional and bending loads. [8]

2.3.6 Maximum Permissible Working Stresses for Transmission Shaft

According to American Society of Mechanical Engineers (ASME) code for the design of transmission shafts, the maximum permissible working stresses in tension or compression may be taken as :

(a) 112 MPa for shafts without allowance for keyways.
(b) 84 MPa for shafts with allowance for keyways.

For shafts purchased under definite physical specifications, the permissible tensile stress (σt) may be taken as 60 per cent of the elastic limit in tension (σel), but not more than 36 per cent of the ultimate tensile strength (σu). In other words, the permissible tensile stress,

$$\sigma t = 0.6\ \sigma el \text{ or } 0.36\ \sigma u, \text{ whichever is less.}$$

The maximum permissible shear stress may be taken as

(a) 56 MPa for shafts without allowance for key ways.
(b) 42 MPa for shafts with allowance for keyways.

For shafts purchased under definite physical specifications, the permissible shear stress (τ) may be taken as 30 percent of the elastic limit in tension (σel) but not more than 18 per cent of the ultimate tensile strength (σu). In other words, the permissible shear stress,

$$\tau = 0.3\ \sigma el \text{ or } 0.18\ \sigma u, \text{ whichever is less. [8]}$$

2.3.7 Design of Shaft

The shafts may be designed on the basis of strength, rigidity, and stiffness. In designing shafts on the basis of strength, the following cases may be considered :

a) Shafts subjected to twisting moment or torque only,

b) Shafts subjected to bending moment only,
c) Shafts subjected to combined twisting and bending moments, and
d) Shafts subjected to axial loads in addition to combined torsional and bending loads. [8]

Below are the procedures for design a shaft : [6]

a) Determining the rotafional speed of the shaft.
b) Determining the power or the torque to be transmitted by the shaft.
c) Determining the design of the power-transmitfing components or other devices that will be mounted on the shaft, and specify the required location of each device.
d) Specifying the location of bearings to support the shaft. Normally two and only two bearings are used to support a shaft.
e) Proposing the general form of the geometry for the shaft, considering how each element on the shaft will be held in position axially and how power transmission from each element to the shaft is to take place.
f) Determining the magnitude of torque that the shaft sees at all points.
g) Determining the forces that are exerted on the shaft, both radially and axially.
h) Resolving the radial forces into components in perpendicular directions, usually vertically and horizontally.
i) Solving for the reactions on all support bearings in each plane.
j) Producing the complete shearing force and bending moment diagrams to determine the distribution of bending moments in the shaft.

k) Selecting the material from which the shaft will be made, and specifying its condition

2.3.8 Calculation of Force on The Shaft

Determining the diameter of the shaft, first of all we need to know the forces acting on the shaft. For example, in the case of loading on horizontal axis with the pulley B and C below, force to the shaft can be illustrated by this Figure.

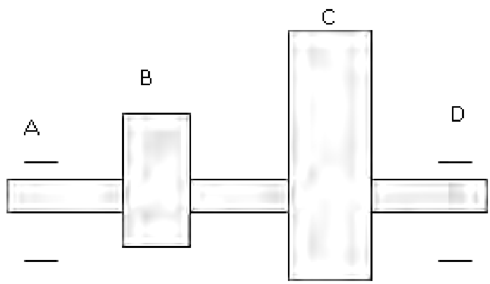


Figure 2.4 Shaft and Pulley

From Figure 2.4 above torque at B who work throughout BC can be calculated by the following equation.

$$T_B = \frac{63000 \text{ x HP}}{n} \quad [2.1]$$

where,

T_B = torque at B who work throughout BC (lb.in)
HP = power works on pulley B (HP)
n = rotating speed motor (rpm)

After the torque on the B and C obtained then calculate for the forces (F) on each pulley with torque moment by the following equation.

$$(F_1 - F_2)\frac{D}{2} = T_B \qquad [2.2]$$

where,
T_B = torque at B who work throughout BC (lb.in)
F_1 F_2 = force on the pulley B (lb)
D = diameter pulley (in)

From equation [2.1] and [2.2] will be known torque and the forces on the shaft, so that the figure would be like below.

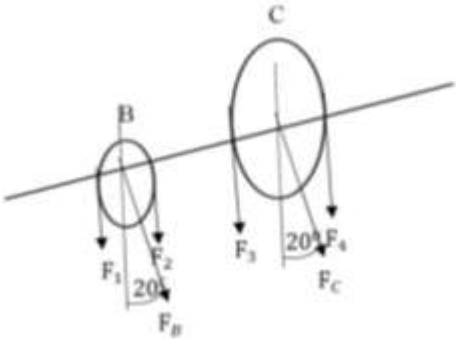


Figure 2.5 Forces on The Shaft

2.3.9 Calculation Reaction Force and Moment Area Horizontal

After the forces along the axis is known, the next step calculate the reaction force on the horizontal direction of the shaft as in Figure 2.5.

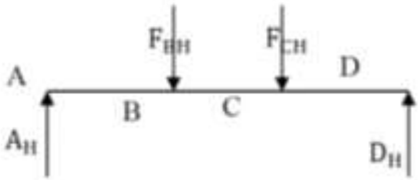


Figure 2.6 Horizontal Reaction Force

From Figure 2.5 the value of A_H and D_H will obtained by using sigma moment (ΣM) and sigma forces (ΣF). A_H value obtained by the following equation.

$$\Sigma M_D = 0$$
$$A_H(AD) - F_{BH}(BD) - F_{CH}(CD) = 0 \qquad [2.3]$$

where,
A_H = horizontal force that works at point A (lb)
AD = distance from point A to D (in)

and D_H value obtained by the following equation.

$$\Sigma F = 0$$
$$A_H - F_{BH} - F_{CH} + D_H = 0 \qquad [2.4]$$

where,
D_H = horizontal force that works at point D (lb)

So, the diagram of moments will obtained like figure below.

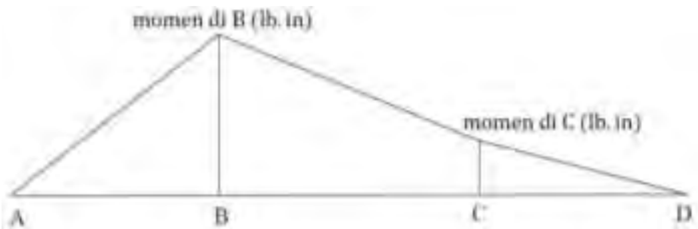


Figure 2.7 Moment Area Horizontal

2.3.10 Calculation Reaction Force and Moment Area Vertical

The next step is to calculate the reaction force on the vertical direction of the shaft as in Figure 2.8

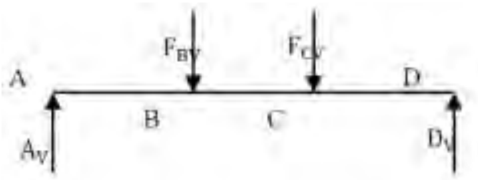


Figure 2.8 Vertical Reaction Force

From Figure 2.7 the value of A_V and D_V will obtained by using sigma moment (ΣM) and sigma forces (ΣF). A_V value obtained by the following equation.

$$\Sigma M_D = 0$$
$$A_V(AD) - F_{BV}(BD) - F_{CV}(CD) = 0 \qquad [2.5]$$

where,

A_V = vertical force that works at point A (lb)

AD = distance from point A to D (in)

and D_V value obtained by the following equation.

$$\Sigma F = 0$$
$$A_V - F_{BV} - F_{CV} + D_V = 0 \qquad [2.6]$$

where,

D_V = vertical force that works at point D (lb)

So, the diagram of moments will obtained like figure below.

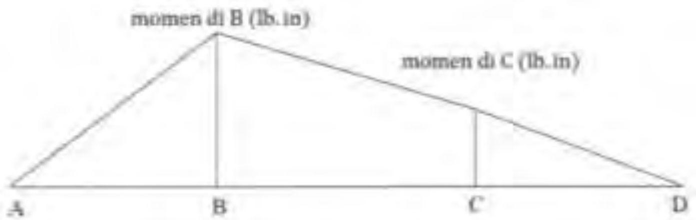


Figure 2.9 Moment Area Vertical

2.3.11 Calculation Shaft Dimension

After all forces that works on the shaft are calculated, the next step is determining the dimensions of the shaft. First, the maximum bending moments should to be known. To determine maximum moment in point B or point C of the Figure 2.9 can be calculated by the following equation.

$$M_B = \sqrt{{B_V}^2 + {B_H}^2} \qquad [2.7]$$

where,
M_B = bending moment maximum (lb.in)
B_V = bending moment vertical (lb.in)
B_H = bending moment horizontal (lb.in)

The result of equation [2.7] will get the maximum bending moment (Mmax) at point B or C. Afterthat, the equivalent twisting moment of the shaft can be calculated by equation [2.8] by entering maximum bending moment and maximum torque working on the system.

$$\mathrm{Te} = \sqrt{\mathrm{Mmax}^2 + \mathrm{Tmax}^2} \qquad [2.8]$$

where,
Te = equivalent twisting moment
T_{max} = torsion moment maximum
M_{max} = bending moment maximum

First, based on the theory of maximum shear stress which to find the shaft diameter based on the bending moment and torque that occur can use below equation.[8]

$$\mathrm{Te} = \frac{\pi}{16} \times \tau \times {d_0}^3 \times (1 - k^4) \qquad [2.9]$$

where,

$$\tau = \frac{\text{Sus}}{\text{N}} \qquad [2.10]$$

Sus = ultimate shear stress material = 0,75 Sut
N = safety factor (*sf*)
τ = torsional shear stress
k = ratio of inside dan outside shaft diameter

The result from the equation [2.9] and [2.10] will get the value of safety factor on the shaft diameter based on maximum shear theory.

Second, the analysis conducted by maximum normal stress theory happens to the shaft, it can be calculated by following equation.[8]

$$\text{Me} = \frac{1}{2}(\text{Mmax} + \sqrt{\text{Mmax}^2 + \text{Tmax}^2}) \qquad [2.11]$$

where,
Me = equivalent bending moment
T_{max} = torsion moment maximum
M_{max} = bending moment maximum

From the equation [2.11], the equivalent bending moment is equal to the following equation.

$$\text{Me} = \frac{\pi}{32} \text{ x } \sigma_b \text{ x } d_o^3 \text{ x } (1 - k^4) \qquad [2.12]$$

where,

$$\sigma_b = \frac{\text{Sut}}{\text{N}} \qquad [2.13]$$

Sut = ultimate strength material
N = safety factor (*sf*)
σ_b = bending stress
k = ratio of inside dan outside shaft diameter

The result from the equation [2.11] and [2.12] will get the value of safety factor on the shaft diameter based on maximum normal stress theory.

Third, the analysis subjected to fluctuating load, such as axial load, fluctuating torque, and bending moment on the shaft, for the equivalent twisting moment can be calculated by following equation.[8]

$$Te = \sqrt{(K_m \text{ x } M)^2 + (K_t \text{ x } T)^2}$$

and equal with $Te = \frac{\pi}{16} \text{ x } \tau \text{ x } {d_o}^3 \text{ x } (1 - k^4)$ [2.14]

where,
Te = equivalent twisting moment
T = twisting moment
M = bending moment
K_m = combined shock and fatigue factor for bending
K_t = combined shock and fatigue factor for torsion

For the equivalent bending moment can be calculated by following equation.

$$Me = \frac{1}{2}\left[K_m \text{ x } M + \sqrt{(K_m \text{ x } M)^2 + (K_t \text{ x } T)^2}\right]$$

and equal with $Me = \frac{\pi}{32} \text{ x } \sigma_b \text{ x } {d_o}^3 \text{ x } (1 - k^4)$ [2.15]

where,
Me = equivalent bending moment
T = twisting moment
M = bending moment
K_m = combined shock and fatigue factor for bending
K_t = combined shock and fatigue factor for torsion

The following table shows the recommended values for Km and Kt.

Table 2.2 Recommended values for *Km* and *Kt*

Nature of load	***Km***	***Kt***
1. Stationary shafts		
a) Gradually applied load	1.0	1.0
b) Suddenly applied load	1.5 to 2.0	1.5 to 2.0
2. Rotating shafts		
a) Gradually applied or steady load	1.5	1.0
b) Suddenly applied load with minor shocks only	1.5 to 2.0	1.5 to 2.0
c) Suddenly applied load with heavy shocks	2.0 to 3.0	1.5 to 3.0

Beside some of the methods above, in determining the diameter of the shaft, also can use the equation Distortion Energy Theory (*Machine Design, Deutcnman*), the following equation [9].

$$\frac{S_{yp}}{N} \geq \frac{32}{\pi D_o^3\left(1-\left(\frac{D_i}{D_o}\right)^4\right)}\left[\left(M_m+\left(\frac{S_{yp}}{S_e}M_r\right)^2\right)+\frac{3}{4}\left(T_m+\frac{S_{syp}}{S_e}T_r\right)^2\right]^{1/2} \quad [2.16]$$

where,

M_m = bending moment average (lb in)

M_r = bending moment range (lb in)

T_m = torsion moment average (lb in)

T_r = torsion moment range (lb in)

$$S_e \quad : C_r.C_s.C_f..\frac{1}{K_f} \quad [2.17]$$

$$S_{es} \quad : C_r.C_s.C_f..\frac{1}{K_{fs}}.S'_s \qquad [2.18]$$

where,

K_f = concentration for bending stress
K_{fs} = concentration for shear stress
S_{yp} = yield point material (psi)
S_{syp} = 0.5
S_{yp} = yield point shear (psi)
C_r = reliability factor
C_s = size correction factor
C_f = surface correction factor
S'_n = endurance limit

2.4 Bearing

A bearing is a machine element which support another moving machine element (known as journal). It constrains relative motion to only the desired motion and reduces friction between moving parts. It permits a relative motion between the contact surfaces of the members, while carrying the load. A little consideration will show that due to the relative motion between the contact surfaces, a certain amount of power is wasted in overcoming frictional resistance and if the rubbing surfaces are in direct contact, there will be rapid wear.

In order to reduce frictional resistance and wear and in some cases to carry away the heat generated, a layer of fluid (known as lubricant) may be provided. The lubricant used to separate the journal and bearing is usually a mineral oil refined from petroleum, but vegetable oils, silicon oils, greases etc., may be used.

The design of the bearing may, for example, provide for free linear movement of the moving part or for free rotation around a fixed axis; or, it may prevent a motion by controlling the vectors of normal forces that bear on the moving parts. Many bearings also facilitate the desired motion as much as possible, such as by minimizing friction. Bearings are classified broadly according to the type of operation, the motions allowed, or to the directions of the loads (forces) applied to the parts. The following are important from the subject point of view :

1. Depending upon the direction of load to be supported. The bearings under this group are classified as Radial bearings and Thrust bearings. In radial bearings, the load acts perpendicular to the direction of motion of the moving element as shown in Figure 2.9 (*a*) and (*b*). In thrust bearings, the load acts along the axis of rotation as shown in 2.9 (*c*).[8]

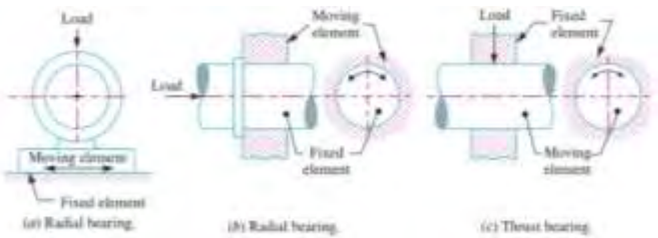


Figure 2.10 Radial and Thrust Bearing

A thrust bearing is used to guide or support the shaft which is subjected to a load along the axis of the shaft. Such type of bearings are mainly used in turbines and propeller shafts.

2. Depending upon the nature of contact. The bearings under this group are classified as Sliding contact

bearings and Rolling contact bearings. In sliding contact bearings, as shown in Figure 2.10 (a), the sliding takes place along the surfaces of contact between the moving element and the fixed element. The sliding contact bearings are also known as plain bearings. In rolling contact bearings, as shown in Figure 2.10 (b), the steel balls or rollers, are interposed between the moving and fixed elements. The balls offer rolling friction at two points for each ball or roller.

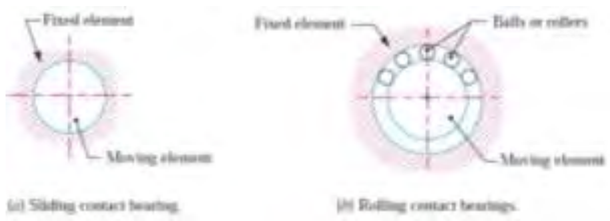


Figure 2.11 Sliding and Rolling Contact Bearing

2.4.1 Thrust Ball Bearing

The thrust ball bearings are used for carrying thrust loads exclusively and at speeds below 2000 r.p.m. At high speeds, centrifugal force causes the balls to be forced out of the races. Therefore at high speeds, it is recommended that angular contact ball bearings should be used in place of thrust ball bearings.

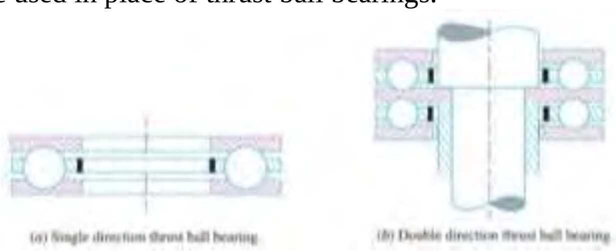


Figure 2.12 Thrust Ball Bearing

2.5 Shaft Coupling

A coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power. Shafts are usually available up to 7 metres length due to inconvenience in transport. In order to have a greater length, it becomes necessary to join two or more pieces of the shaft by the coupling. Couplings do not normally allow disconnection of shafts during operation, however there are torque limiting couplings which can slip or disconnect when some torque limit is exceeded.

Shaft couplings are used in machinery for several purposes, the most common of which are the following :

- To provide for the connection of shafts of units that are manufactured separately such as a motor and generatorand to provide for disconnection for repairs or alternations.
- To provide for misalignment of the shafts or to introduce mechanical flexibility.
- To reduce the transmission of shock loads from one shaft to another.
- To introduce protection against overloads.

By careful selection, installation and maintenance of couplings, substantial savings can be made in reduced maintenance costs and downtime.

A shaft coupling also should have the requirements such as, it should be easy to connect or disconnect, can transmit the full power from one shaft to the other shaft without losses, hold the shafts in perfect alignment, can reduce the transmission of shock loads from one shaft to another shaft, and should have no projecting parts.

Shaft coupling are divided into two main groups, those are Rigid coupling and Flexible coupling. Rigid coupling is used to connect two shafts which are perfectly aligned. Types of rigid coupling are important from the subject point of view such as sleeve or muff coupling, clamp or split-muff or compression coupling, and flange coupling. Flexible coupling is used to connect two shafts having both lateral and angular misalignment. Types of flexible coupling are important from the subject point of view such as bushed pin type coupling, universal coupling, and oldham coupling. A flexible coupling is used so as to permit an axial misalignemnt of the shaft without undue absorption of the power which the shaft are transmitting.

Figure 2.13 Flexible Coupling

2.6 Material Properties

The mechanical properties can be interpreted as a response against the loading of a given material, such as force, torque, or a combination of both. In practices, loading on material devided into two, they are static loads and dynamic loads. The difference between them only in function of time where the static load is not influenced by the function of time while the dynamic loads influenced by the function of time.

2.6.1 Deformation

Deformation is a change in terms of dimensions and position of a material caused by natural circumstances or the excessive loads and work in the scale of time and space. Factors that control the deformation:

- Temperature and pressure in all directions
- Speed of movement

Deformation is divided into two, namely, the elastic deformation and plastic deformation. Elastic deformation is a temporary change in shape. Changes will be lost when the force is removed. In other words, when the load is removed, then the object will return to forms and original size. Meanwhile, plastic deformation is a permanent change in shape, though the load is removed.[6]

2.6.2 Elasticity

Elasticity is a properties of an object or material to get return into the origin shape. Based on the elasticity, the material can be divided into elastic material and plastic materials. The plastic material is a material which can return to its original shape if the force acting on it removed. While the plastic material is a material that can not be returned to its original shape after the force acting on it removed.[6]

2.7 Material Mechanical Properties

Machine elements are very often made from one of the metals or metal alloys such as steel, aluminum, cast iron, zinc, titanium, or bronze. There are some important properties of materials as they affect mechanical design.

Strength, elastic, and ductility properties for metals, plastics, and other types of materials are usually determined from a tensile test in which a sample ofthe material, typically in the form of a round or flat bar, is clamped between jaws and pulled slowly until it breaks in tension. The magnitude of the force on the bar and the corresponding change in length (strain) are monitored and recorded continuously during the test. Because the stress in the bar is equal to the applied force divided by the area, stress is proportional to the applied force. The data from such tensile tests are often shown on stress-strain diagrams, such as in Figures 2.13. [6]

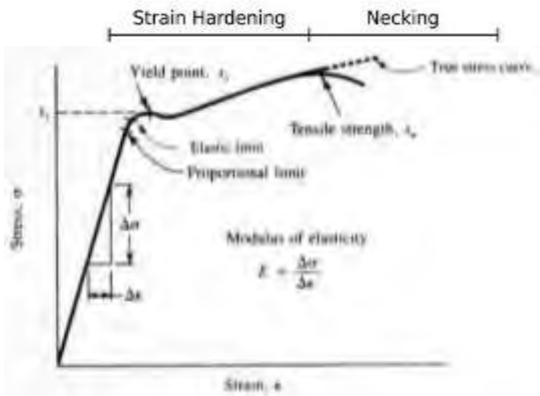


Figure 2.14 Typical Stress – Strain Diagram for Steel

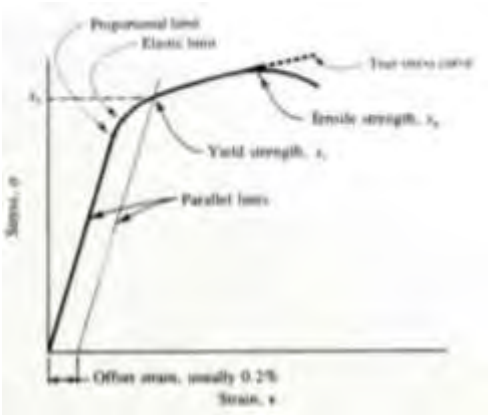


Figure 2.15 Typical Stress – Strain Diagram for Aluminium and other metals having no yield point

2.7.1 Hardness

Hardness is defined as the resistance of a material to indentation/permanent penetration due to dynamic or static load.

2.7.2 Tensile Strength, s_u

The peak of the stress-strain curve is considered the ultimate tensile strength (s_u), sometimes called the ultimate strength or simply the tensile strength. At this point during the test, the highest apparent stress on a test bar of the material is measured. As shown in Figures 2.14, the curve appears to drop off after the peak. The apparent stress is computed by dividing the load by the original cross-sectional area of the test bar. After the peak of the curve is reached, there is a pronounced decrease in the bar's diameter, refened to as *necking down.* Thus, the load acts over a smaller area, and the *actual stress* continues to increase until failure. [6]

2.7.3 Yield Strength, s_y

Yield strength is an overview of material ability to resist permanent deformation when used in structural usage involving mechanical loading such as pull, press, bending, or twisting, in other words, where there is a large increase in strain with little or no increase in stress. Figure 2.14 shows the stress-strain diagram form that is typical of a nonferrous metal such as aluminum or titanium or of certain high-strength steels. There is no pronounced yield point, but the material has actually yielded at or near the stress level indicated as s_y. That point is determined by the *offset method,* in which a line is drawn parallel to the straight-line portion of the curve and is oft'set to the right by a set amount, usually 0.20% strain (0.002 in/in). The intersection of this line and the stress-strain curve defines the material's yield strength.[6]

2.7.4 Modulus of Elasticity

Modulus of elasticity (E) is the ratio of stress to strain. The greater the elastic modulus, the greater the stress to a particular strain. Comparison of tensile stress to tensile strain, for a given material, the same as the ratio of compression stress against compression strain. This comparison is called the modulus of strain or young modulus, denoted by E. [6]

$$E = \frac{\text{stress}}{\text{strain}} = \frac{\text{compression stress}}{\text{compression strain}}$$

$$E = \frac{Fn/A}{\Delta l/lo} = \frac{loFn}{A\Delta l} \qquad [2.19]$$

$$E = \frac{\sigma}{e} \qquad [2.20]$$

where,

E = young modulus

Fn = force (N)

A = cross sectional area of bar (m^2)

Δl = change in length of bar (m)

lo = initial length (m)

2.8 Stresses

Stress is known when some external system of forces or loads act on a body, the internal forces (equal and opposite) are set up at various sections of the body, which resist the external forces. This internal force per unit area at any section of the body is known as ***unit stress*** or simply a ***stress.*** In the other words, reaction force or a force to return to its original form which occurs in a material and can not be calculated without involving force occurs.

2.8.1 Normal Stress

Normal stress is the intensity of the forces acting in perpendicular direction to the part that is stressed, and denoted by σ (sigma). When external forces acting on a block is parallel to the main axis and pieces of the block cross-section is constant, so the internal stress that produced and parallel to the axis is called axial force. In this figure below shows a block of material get some force.

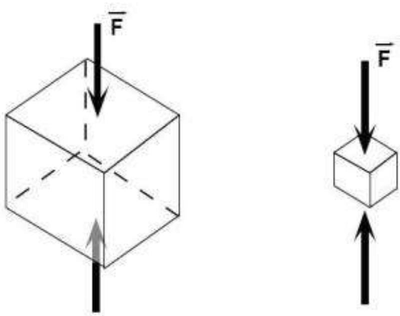


Figure 2.16 Material Block

Stress that occurs in the material block can be written as,

$$\text{Stress} = \sigma = \frac{F}{A} \qquad [2.21]$$

where,

σ = stress (N/m^2)
F = force (N)
A = section area (m^2)

2.8.2 Tensile Stress

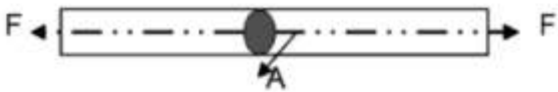


Figure 2.17 Tensile Stress on Block

The equation of tensile stress can be written as,

$$\sigma_t = \frac{F}{A} = \frac{F_a}{A} \qquad [2.22]$$

where,

σ_t = tensile stress (N/m^2)
F = force (N)
A = section area (m^2)

2.8.3 Compressive Stress

The compressive stress occurs when a block was given force F opposite each other and located in one line. The equation of compressive stress can be written as,

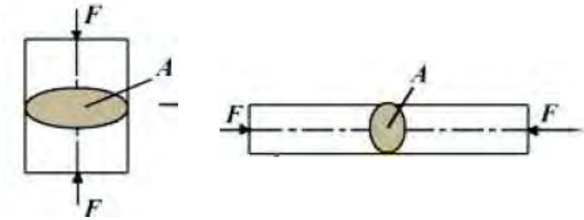


Figure 2.18 Comprassive Stress on Block

$$\sigma_D = \frac{F}{A} = \frac{F_a}{A} \qquad [2.23]$$

where,
σ_D = compressive stress (N/m^2)
F = force (N)
A = section area (m^2)

2.8.4 Shear Stress

Shear stress occurs when an object works with two forces in the opposite direction, perpendicular to the axis of the block, the force is not in one line but there is no moment on its section area.

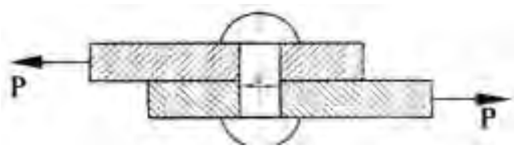


Figure 2.19 Shear Stress on Block

In the figure above, two force F (P) are equal in opposite directions. Force F (P) worked evenly distributed in cross section A. The shear stress can be calculated by,

$$\tau = \frac{F}{A} \quad (N/m^2) \qquad [2.24]$$

where,

τ = shear stress (N/m^2)
F = force (N)
A = section area (m^2)

2.8.5 Strain

Strain is the change in the size of the object because the forces in equilibrium compared to the original size. Strain can also describe as the degree of deformation. The deformation rate can be elongated, shortened, enlarge, shrink, and so on.

$$\varepsilon = \frac{\Delta L}{L} \qquad [2.25]$$

where,

ε = strain
ΔL = change in length (m)
L = initial length (m)

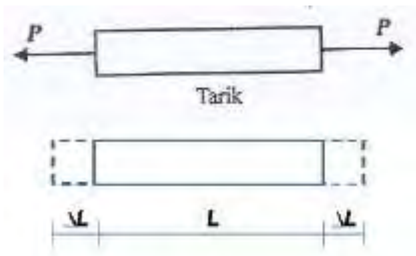


Figure 2.20 Strain on Material Block

2.9 Load

Load is defined as any external force acting upon a machine part. The following four types of the load are important from the subject point of view :

1. Dead or steady load.
   A load is said to be a dead or steady load, when it does not change in magnitude or direction, due to gravity fixed position. Which includes the dead load are the weight of the structure itself, other equipment on the structure and fixed.
2. Live or variable load.
   A load is said to be a live or variable load, when it changes continually. Example : human and the equipment that can be moved.
3. Suddenly applied or shock loads.
   A load is said to be a suddenly applied or shock load, when it is suddenly applied or removed.
4. Impact load.
   A load is said to be an impact load, when it is applied with some initial velocity.

2.10 Safety Factor (*sf*)

Factor of safety is defined as the ratio of the maximum stress to the working stress. Mathematically,

$$\text{Safety Factor} = \frac{\text{Maximum Stress}}{\text{Working or Design Stress}}$$

The selection of a proper factor of safety to be used in designing any machine component depends upon a number of considerations, such as the material, mode of manufacture, type of stress, general service conditions and shape of the parts. Before selecting a proper factor of safety, a design engineer should consider the following points :

- The reliability of the properties of the material and change of these properties during service,
- The reliability of test results and accuracy of application of these results to actual machine parts,
- The reliability of applied load,
- The certainty as to exact mode of failure,
- The extent of simplifying assumptions,
- The extent of localised stresses,
- The extent of initial stresses set up during manufacture,
- The extent of loss of life if failure occurs, and
- The extent of loss of property if failure occurs.

2.11 Finite Element Analysis Method

Finite Element Analysis, commonly called FEA, is a method of numerical analysis. FEA is used for solving problems in many engineering disciplines such as machine design, acoustics, electromagnetism, soil mechanics, fluid dynamics, and many others. In mathematical terms, FEA is a numerical technique used for solving field problems described by a set of partial differential equations.[2]

FEA is a powerful engineering analysis tool useful in solving many problems ranging from very simple to very complex. Design engineers use FEA during the product development process to analyze the design-in-progress. Time constraints and limited availability of product data call for many simplifications of computer models.

Finite Element Methode overcomes the disadvantages of traditional methode by providing a systematic procedue for the derivation of approximiation function over subregions of the domain.

Finite Element Methods have 3 basic feature :

1. Geomatrical complex domain of the problem is represent as a collection of geomatrical simple subdomains.
2. Each Finite Element derived using the basicidea that can be represented by a linear combination of algebraic polynomials.
3. Algrebaic relation among the undetermined coefficient.

When the FEM is applied to a specific field of analysis (like stress analysis, thermal analysis, or vibration analysis) it is often referred to as finite element analysis (FEA). An FEA is the most common tool for stress and structural analysis. Various fields of study are often related. For example, distributions of non-uniform temperatures induce non-obvious loading conditions on solid structural members. Thus, it is common to conduct a thermal FEA to obtain temperature results that in turn become input data for a stress FEA. FEA can also receive input data from other tools like motion (kinetics) analysis systems and computation fluid dynamics systems.

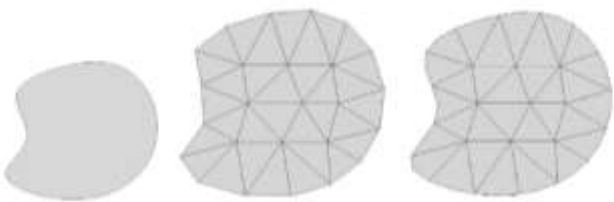


Figure 2.21 Finite Element Concept

The basic concept behind the FEM is to replace any complex shape with the union (or summation) of a large number of very simple shapes (like triangles) that are combined to correctly model the original part or an area crudely meshed with linear and quadratic triangles. The smaller simpler shapes are called finite elements because each one occupies a small but finite sub-domain of the original part.

Figure 2.21 shows the finite element concept that from complex area than divided ito enclosed set of triangle that will integrared and sum the areas of the single small sub-domain into complex domain.

FEA converts scalar integrals to matrix expressions by assuming a spatial interpolation between the nodes of a typical element for items of interest, such as positions, displacements, velocities, or temperatures [2].

CHAPTER 3
RESEARCH METHODS

In order to solve the problem above, that will be used data analysis from literatures.

1. LITERATURE STUDY

Literature study was performed by collecting various references to support this final project. The media that will used is :

a. Books;
b. Journals;
c. Engineering Report;
d. Thesis

The primary concern for this literature study is transmission shaft for vertical axis turbine, design of shaft, calculation of shaft and other support component, and finite element methods.

2. SHAFT CALCULATION

At this stage will performed the calculation steps to determine the dimension of shaft. Before calculating, should be known the input parameter of turbine based on trials that have been conducted. The permanent variable is the power of turbine, 5 KW. The variation variable are 3 materials that will be used on shaft. The calculation steps are :

a. Determining the rotafional speed of the shaft.
b. Determining the power or the torque to be transmitted by the shaft.
c. Determining the design of the power-transmitting components or other devices that will be mounted on the shaft, and specify the required location of each device.

d. Specifying the location of bearings to support the shaft.
e. Determining the magnitude of torque that the shaft sees at all points.
f. Determining the forces that are exerted on the shaft, both radially and axially.
g. Resolving the radial forces into components in perpendicular directions, usually vertically and horizontally.
h. Solving for the reactions on all support bearings in each plane.
i. Producing the complete shearing force and bending moment diagrams to determine the distribution of bending moments in the shaft.
j. Selecting the material from which the shaft will be made, and specify its condition

3. MODELING

At this stage, modeling will perform using solid modeling Computer Aided Engineering (CAE). Dimension of shaft is based on shaft calculation and specification determined.

4. RUNNING SIMULATION

Running simulation will performed by giving spesific rotating speed to the vertical axis turbine shaft and the others input data for material and properties to perform meshing and analyze the stress, strain, deformation of vertical axis turbine shaft. This final project will perform simulation using Finite Element Analysis Methods.

5. DATA ANALYSIS

Data from literature study and running simulation such as stress, strain, safety factor, and deformation will analyze to know the strength analysis of vertical axis turbine shaft using FEAM that implemented in Solidwork Simulation.

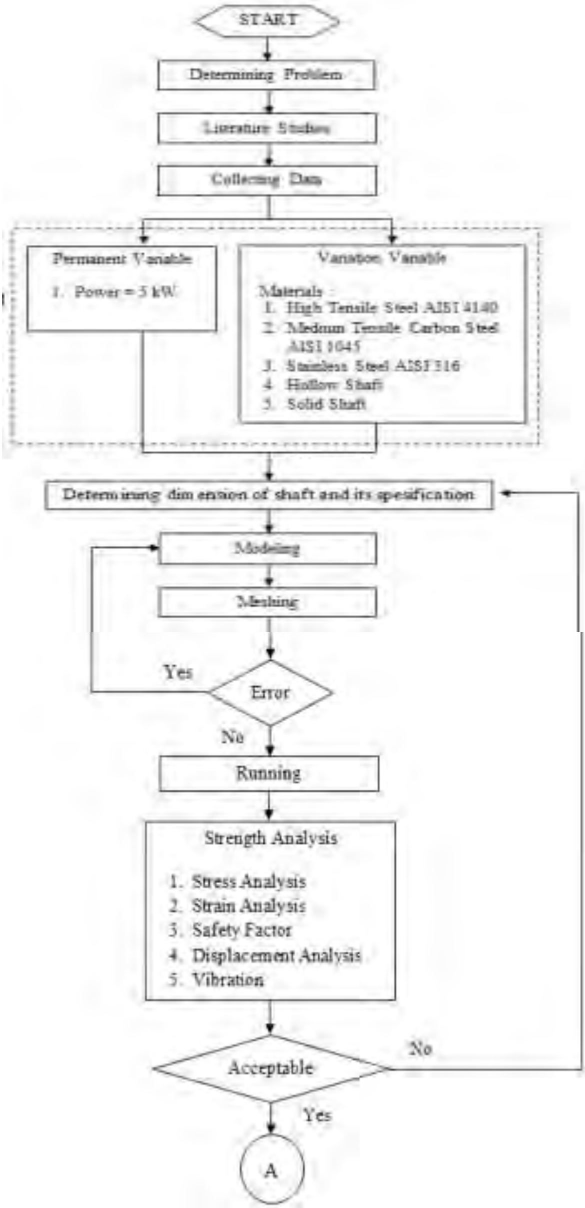
6. OUTPUT ANALYSIS

The output data from this final project based on Finite Element Analysis Methods is Stress, Strain, Safety Factor, and Displacement of Vertical Axis Turbine Shaft.

7. CONCLUSION & REPORTING

At the end of stages will inform about the strength analysis of vertical axis turbine shaft and also the dimension and its spesification, as a transmission shaft for mechanical transmission system that capable for 5 kW capacity on ocean current power plant

8. METHODOLOGY FLOW CHART


START
Determining Problem
Literature Studies
Collecting Data
Permanent Variable
1. Power = 5 kW
Variation Variable
Materials :
1. High Tensile Steel AISI 4140
2. Medium Tensile Carbon Steel AISI 1045
3. Stainless Steel AISI 316
4. Hollow Shaft
5. Solid Shaft
Determining dimension of shaft and its spesification
Modeling
Meshing
Error
Yes
No
Running
Strength Analysis
1. Stress Analysis
2. Strain Analysis
3. Safety Factor
4. Displacement Analysis
5. Vibration
Acceptable
No
Yes
A

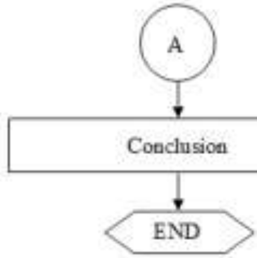


Figure 3.1 Research Methods

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CHAPTER 4
DATA ANALYSIS

4.1 Analysis of Ocean Current Platform Concept

Ocean currents platform are offshore building convert ocean currents into electric energy with utilizing the rotation of the ocean current turbine. There are several types of platforms for ocean current power plant. One of the types is TLP (Tension Light Platform). TLP is a platform with a simple type of box. Figure 4.1 shows the concept of this ocean current platform.

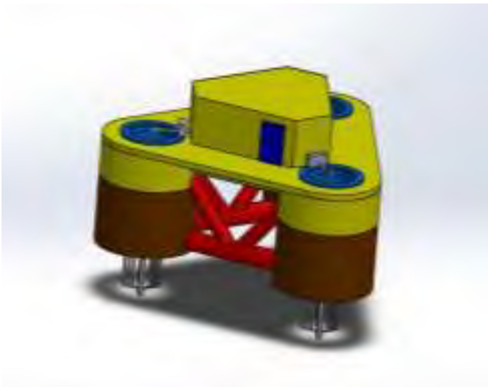


Figure 4.1 Tension Light Platform

Determining the type of platform used will require consideration based on certain parameters. The one of parameters is power that can be generated. When using a platform, the number of turbines that can be used on a platform will determine the amount of power generated. If on some platform have the same number of turbines, so the next thing should be reviewed is the result of the current in the area around it. Spacing of each turbine is also influental. Tension Leg Platform (TLP) can use three turbines on the platform and the spacing of three turbines are not too close. The direction of the ocean currents that uncertainty will also affect the condition of the platform. When viewed from many aspects, the best choice can be used is TLP because TLP can receiving current from all directions.

4.2 Analysis of Vertical Axis Turbine Concept

Vertical axis turbine (VAT) has a rotational axis that is perpendicular to the direction of fluid flow. In the application at sea, vertical turbine can transmit torque directly to the surface of the water without complex transmission systems under the sea. The characteristic of this turbine has a very high starting torque that can start the turbine rotation spontaneously without another help.

Turbine that used in this concept is VAT with Darrieus types. Based on the previous research by CFD (Computational Fluid Dynamics), airfoil type for turbine that chosen is NACA 0018 with simetry airfoil and 9 blades.

Figure 4.2 Darrieus Turbine Model – NACA 0018

NACA 0018 airfoil type is best for NACA series and commonly used for Darrieus turbine because this foil has a thickness to chord ratio is relatively high, so it has good strength to resist bending. Furthermore, NACA 0018 has the best characteristics for vertical axis turbine of ocean currents.

4.3 Vertical Axis Turbine (VAT) Shaft

Plan of vertical axis turbine shaft is arranged by a series of three shafts having a length respectively 3.3 m, 2 m and 2 m and connected by flexible coupling are shown in Figure 4.3. There is no provision and calculation to determine the length of shaft.

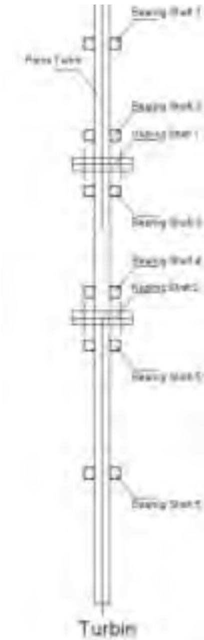


Figure 4.3 Turbine Shaft

The calculation of shaft diameter can be determined by this following equation.

$$D = \left[\frac{32N}{\pi}\sqrt{\left[\frac{K_t M}{S'_n}\right] + \frac{3}{4}\left[\frac{T}{S_y}\right]^2}\right]^{\frac{1}{3}} \qquad [4.1]$$

From that equation, the amount of torsion and bending moment on the shaft should be known.

4.4 Designing of Vertical Axis Turbine Shaft

4.4.1 Shaft Material

The variation variable of this research is the material. It will compare three different materials and the form of the shaft, round bar (solid) or hollow. The materials that used to compare are :

1. High Tensile Steel AISI 4140
2. Medium Tensile Carbon Steel AISI 1045
3. Stainless Steel AISI 316.

From the following result of calculation and analysis, the shaft material that recommended to be used is High Tensile Steel AISI 4140 that have 1% chromium-molybdenum medium hardenability. The ultimate tensile strength (s_u) of the material is 850 – 1000 Mpa and the yield strength (s_y) is 665 Mpa.

This shaft material chosen by the reason, the chromium content provides good hardness penetration and the molybdenum content ensures uniform hardness and high strength. Beside that, its also good ductility and good wear resistance.

4.4.2 Shaft Design Calculation

Below is the calculation process to design a turbine shaft.

1) First, determining the turbine paramater. This parameter based on trials that have been conducted.

Torsion (T)	= 1326 Nm
Rotating Speed	= 36 RPM = 3,768 rad/s
R $_{Turbine}$	= 0.8 m
Ft	$= \frac{1326}{0,8} = 1657,5$ N
Power	= 5000 W

2) Determining the maximum torsion and bending moment on the shaft.

Force (Ft) that appear on the turbine, its effect on the shaft 3,3 meter as bending moment. Based on the analysis performed by using MD Solid, it produces the analysis results of force distribution and moment distribution as following figure.

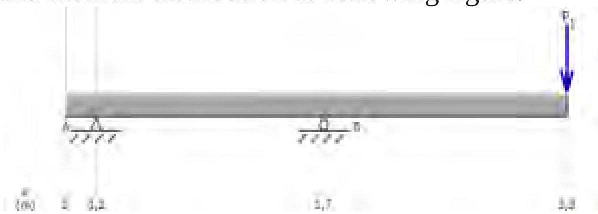


Figure 4.4 Force on Turbine Shaft

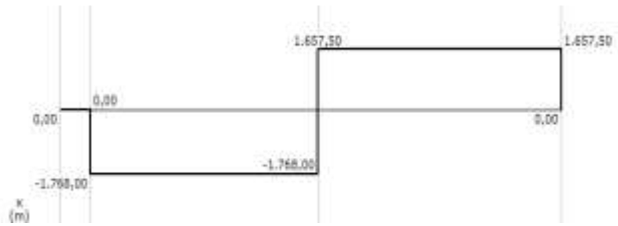


Figure 4.5 Distribution Shear Force

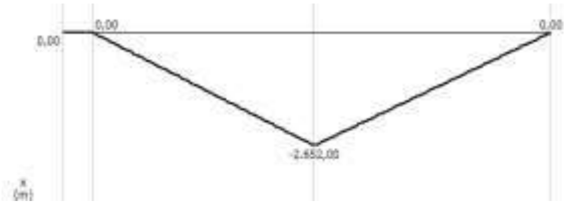


Figure 4.6 Moment Diagram

The Figure 4.6 shows that maximum bending moment on shaft 1 is 2652 Nm, while based on trial of turbine get the maximum torque 1326 Nm.

Below is the analytical calculation by using Three Moment Equation Theory. The theory is used to find excessive moment in many supports. The equation also called repetitive formula to find every three moment that is undefined.

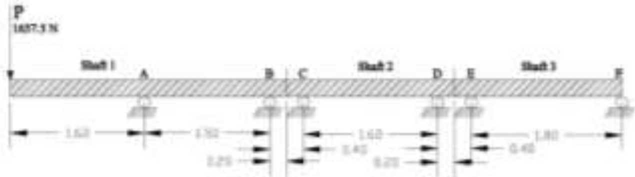
$$L_L M_L + 2\left(L_L + \frac{I_L}{I_R} L_R\right) M_C + \frac{I_L}{I_R} L_R M_R = -P_L ab\left(1 + \frac{a}{L_L}\right) \quad [4.2]$$

where,

L_L = distance on left side from C
L_R = distance on right side from C
M_L = moment on life side
M_C = moment on center
M_R = moment on right side
P_L = force on life side
P_R = force on right side
$I_R = I_L$ = inertia moment (constant)

$$L_L M_L + 2\left(L_L + \frac{I_L}{I_R} L_R\right) M_C + \frac{I_L}{I_R} L_R M_R = -P_R a' b'\left(1 + \frac{a}{L_L}\right) \quad [4.3]$$

The equation [4.2] is for calculate for finding maximum moment on left side. Otherwise, equation [4.3] for finding maximum moment on right side. The detail calculation for this vertical axis turbine shaft using three moment equation is as following.



$M_A = -1657{,}5 \,.\, 1{,}6 = -2652\ Nm$

- Three moment equation for ABC, AB left side and BC right side
  $1{,}5\ \mathrm{M_A} + 2\ (1{,}5 + 0{,}4)\mathrm{M_B} + 0{,}4\ \mathrm{M_C} = 0$
  (0 because there is no other force on left side or right side of B, and also C, D, E, F)
  $1{,}5 \,.\, 2652 + 3{,}8\ \mathrm{M_B} + 0{,}4\ \mathrm{M_C} = 0$
  $3{,}8\ \mathrm{M_B} + 0{,}4\ \mathrm{M_C} = -3978$ ....(1)

- Three moment equation for BCD, BC left side and CD right side
  $0{,}4\ \mathrm{M_B} + 2\ (0{,}4 + 1{,}6)\mathrm{M_C} + 1{,}6\ \mathrm{M_C} = 0$
  $0{,}4\ \mathrm{M_B} + 4\ \mathrm{M_C} + 1{,}6\ \mathrm{M_C} = 0$ ....(2)

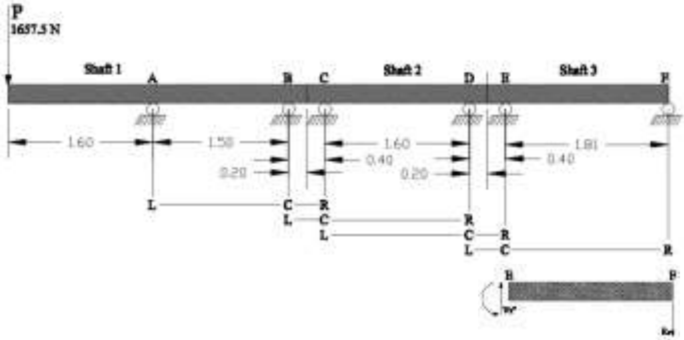
- Three moment equation for CDE, CD left side and DE right side
  $1{,}6\ \mathrm{M_C} + 2\ (1{,}6 + 0{,}4)\mathrm{M_D} + 0{,}4\ \mathrm{M_E} = 0$
  $1{,}6\ \mathrm{M_C} + 4\ \mathrm{M_D} + 0{,}4\ \mathrm{M_E} = 0$......................(3)

- Three moment equation for DEF, DE left side and EF right side, $\mathrm{M_F} = 0$ because on the end of shaft.
  $0{,}4\ \mathrm{M_D} + 2\ (0{,}4 + 1{,}8)\mathrm{M_E} + 1{,}8\ \mathrm{M_F} = 0$
  $0{,}4\ \mathrm{M_D} + 4{,}4\ \mathrm{M_E} = 0$......................(4)

The completion of equation (1), equation (2), equation (3), and equation (4) by doing elimination and substitution will result :
$\mathrm{M_A} = -1657{,}5 \,.\, 1{,}6 = -2652\ \mathrm{Nm}$
$\mathrm{M_B} = -1060{,}24\ \mathrm{Nm}$

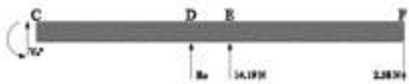
$M_C = 126{,}44$ Nm
$M_D = -51{,}04$ Nm
$M_E = 4{,}64$ Nm
$M_F = 0$

And then, it can be defined the reaction force of each section.

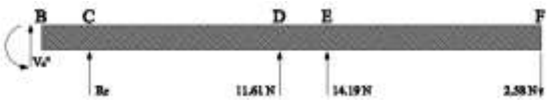


$M_E \quad = 4{,}64$ Nm
$\Sigma M_E = 0$ (clockwise) $\rightarrow 4{,}64 - 1{,}8\ R_F = \ 0$
$\therefore R_F = 2{,}58$ N

$M_D \quad = -51{,}04$ Nm
$\Sigma M_D = 0$ (counterclockwise) $\rightarrow -R_E(0{,}4) + 2{,}58 \,.\, 2{,}2 = \ 0$
$\therefore R_E = -14{,}19$ N



$M_C \quad = 126{,}44$ Nm
$\Sigma M_C \ = 0$ (counterclockwise) $\rightarrow R_D \,.\, 1{,}6 + 14{,}9 \,.\, 2 - 2{,}58 \,.\, 3{,}8 = 0$
$\therefore R_D = 11{,}61$ N



$M_B \quad = -1060{,}24$ Nm
$\Sigma M_B \ = 0$ (counterclockwise)
$- R_C \,.\, 0{,}4 - 11{,}61 \,.\, 2 - 14{,}19 \,.\, 2{,}4 \ + \ 2{,}58 \,.\, 4{,}2 = 0$
$\therefore R_C = -\ 116{,}1$ N

3) Determining shaft diameter and its factor of safety

The variable of this research will compare the shaft was made by hollow bar and round bar (solid shaft). The process of analyzing the safety factor on the shaft can be done based on the following theories.

a) Maximum shear stress theory
b) Maximum normal stress theory
c) Shafts subjected to fluctuating loads

Below is the example of detail calculation for **Hollow Shaft** by three theories. Hollow shaft diameter is planned of inside diameter (di) = 0,035 m and outside diameter (do) = 0,05 m and the material is High Tensile Steel AISI 4140 with ultimate tensile strength (s_u) of the material is 850 – 1000 MPa and the yield strength (s_y) is 665 MPa.

a) Maximum Shear Stress Theory

Maximum shear stress induced due to twisting moment (torque or shear loading).

Known :
Mmax = 2652 Nm
Tmax = 1326 Nm
The equivalent twisting moment (Te) can be calculated by :

$$\mathrm{Te} = \sqrt{\mathrm{Mmax}^2 + \mathrm{Tmax}^2} \qquad [4.2]$$

$$\mathrm{Te} = \sqrt{2652^2 + 1326^2}$$

$$\mathrm{Te} = 2965{,}03\ \mathrm{Nm}$$

Next, the value of safety factor can be determined by :

$$\mathrm{Te} = \frac{\pi}{16}\ \mathrm{x}\ \tau\ \mathrm{x}\ \mathrm{d_o}^3\ \mathrm{x}\ (1 - \mathrm{k}^4) \qquad [4.3]$$

where,

$$\tau = \frac{\text{Sus}}{\text{N}} \qquad [4.4]$$

S_{us} = ultimate shear stress material
= 0,75 S_{ut}
N = safety factor (*sf*)
τ = torsional shear stress
k = ratio of inside and outside shaft diameter = *di* /*do*

So,

$$\text{Te} = \frac{\pi}{16} \text{ x } \frac{\text{Sus}}{\text{N}} \text{ x } d_0^{\,3} \text{ x } (1 - k^4)$$

$$2965{,}03 = \frac{3{,}14}{16} \text{ x } \frac{0{,}75.850000000}{\text{N}} \text{ x } 0{,}05^3 \text{ x } \left(1 - \frac{0{,}035}{0{,}05}^4\right)$$

$\therefore$ N = 4,008

b) Maximum Normal Stress Theory

Maximum normal stress induced due to bending moment (tensile or compressive) or its due to the forces acting upon machine elements like gears, pulleys etc. as well as due to the weight of the shaft itself.

Known :
Mmax = 2652 Nm
Tmax = 1326 Nm

The equivalent bending moment (Me) can be calculated by :

$$\text{Me} = \frac{1}{2}(\text{Mmax} + \sqrt{\text{Mmax}^2 + \text{Tmax}^2})$$

$$\text{Me} = \frac{1}{2}(2652 + \sqrt{2652^2 + 1326^2})$$

$$\text{Me} = 2808{,}5 \text{ Nm}$$

Next, the value of safety factor can be determined by :

$$\text{Me} = \frac{\pi}{32} \text{ x } \sigma \text{ x } d_o^{\,3} \text{ x } (1 - k^4)$$

where,

$$\sigma = \frac{\text{Sut}}{\text{N}}$$

S_{ut} = ultimate strength material
N = safety factor (*sf*)
σ = bending stress
k = ratio of inside dan outside shaft diameter = *di* /*do*

So,

$$\text{Me} = \frac{\pi}{32} \text{ x } \frac{\text{Sut}}{\text{N}} \text{ x } d_0^{\,3} \text{ x } (1 - k^4)$$

$$2808{,}5 = \frac{3{,}14}{32} \text{ x } \frac{850000000}{\text{N}} \text{ x } 0{,}05^3 \text{ x } \left(1 - \frac{0{,}035^4}{0{,}05}\right)$$

$\therefore$ N $= 2{,}82$

c) Shafts Subjected to Fluctuating Loads

The calculation subjected to fluctuating load, such as axial load, fluctuating torque, and bending moment on the shaft.

Known :

Mmax = 2652 Nm
Tmax = 1326 Nm
Km = 1,5
Kt = 1,5

(Value of Km and Kt based on the shaft suddenly applied load with minor shocks only).

The equivalent twisting moment (Te) can be calculated by following equation.

$$\text{Te} = \sqrt{(K_m \text{ x } M)^2 + (K_t \text{ x } T)^2}$$

$$\text{Te} = \sqrt{(1{,}5 \text{ x } 2652)^2 + (1{,}5 \text{ x } 1326)^2}$$

Te = 4447,54 Nm

Next, the value of safety factor can be determined by :

$$\text{Te} = \frac{\pi}{16} \text{ x } \tau \text{ x } d_o^{\,3} \text{ x } (1 - k^4)$$

$$4447{,}54 = \frac{3{,}14}{16} \text{ x } \frac{0{,}75.850000000}{N} \text{ x } 0{,}05^3 \text{ x } \left(1 - \frac{0{,}035}{0{,}05}^4\right)$$

$$N \;= 2{,}672$$

The equivalent bending moment (Me) can be calculated by :

$$Me = \frac{1}{2}\left[K_m \text{ x } M + \sqrt{(K_m \text{ x } M)^2 + (K_t \text{ x } T)^2}\,\right]$$

$$Me = \frac{1}{2}\left[1{,}5 \text{ x } 2652 + \sqrt{(1{,}5 \text{ x } 2652)^2 + (1{,}5 \text{ x } 1326)^2}\right]$$

Me = 4212,77 Nm

Next, the value of safety factor can be determined by :

$$Me \quad = \frac{\pi}{32} \text{ x } \sigma \text{ x } {d_o}^3 \text{ x } (1 - k^4)$$

$$4212{,}77 \; = \frac{3{,}14}{32} \text{ x } \frac{850000000}{N} \text{ x } 0{,}05^3 \text{ x } \left(1 - \frac{0{,}035}{0{,}05}^4\right)$$

$$N \;= 1{,}88$$

∴ Taking the minimum of the two value, so

$$N \;= 1{,}88 \text{ say 2 Ans}$$

Below is the example of detail calculation for **Solid Shaft** by three theories. Solid shaft diameter was planned of 0,05 meter and the material is High Tensile Steel AISI 4140 with ultimate tensile strength (s_u) of the material is 850 – 1000 MPa and the yield strength (s_y) is 665 MPa.

a) Maximum Shear Stress Theory

Maximum shear stress induced due to twisting moment (torque or shear loading).

Known :

Mmax = 2652 Nm

Tmax = 1326 Nm

The equivalent twisting moment (Te) can be calculated by :

$$Te = \sqrt{Mmax^2 + Tmax^2}$$

$$Te = \sqrt{2652^2 + 1326^2}$$

$$Te = 2965{,}03 \text{ Nm}$$

Next, the value of safety factor can be determined by :

$$Te = \frac{\pi}{16} \text{ x } \tau \text{ x } d_o^{\ 3}$$

where,

$$\tau = \frac{Sus}{N}$$

S_{us} = ultimate shear stress material
= 0,75 S_{ut}
N = safety factor (*sf*)
τ = torsional shear stress
So,

$$Te = \frac{\pi}{16} \text{ x } \frac{Sus}{N} \text{ x } d_o^{\ 3}$$

$$2965{,}03 = \frac{3{,}14}{16} \text{ x } \frac{0{,}75.850000000}{N} \text{ x } 0{,}05^3$$

$\therefore$ N = 5,27

b) Maximum Normal Stress Theory

Maximum normal stress induced due to bending moment (tensile or compressive) or its due to the forces acting upon machine elements like gears, pulleys etc. as well as due to the weight of the shaft itself.

Known :
Mmax = 2652 Nm
Tmax = 1326 Nm

The equivalent bending moment (Me) can be calculated by :

$$Me = \frac{1}{2}(Mmax + \sqrt{Mmax^2 + Tmax^2})$$

$$Me = \frac{1}{2}(2652 + \sqrt{2652^2 + 1326^2})$$

$$Me = 2808{,}5 \text{ Nm}$$

Next, the value of safety factor can be determined by :

$$Me = \frac{\pi}{32} \times \sigma_b \times d_o^{\,3}$$

where,

$$\sigma_b = \frac{Sut}{N}$$

S_{ut} = ultimate strength material
N = safety factor (*sf*)
σ = bending stress
So,

$$Me = \frac{\pi}{32} \times \frac{Sut}{N} \times d_o^{\,3}$$

$$2808{,}5 = \frac{3{,}14}{32} \times \frac{850000000}{N} \times 0{,}05^3$$

$$\therefore\ N = 3{,}71$$

c) Shafts Subjected to Fluctuating Loads

The calculation subjected to fluctuating load, such as axial load, fluctuating torque, and bending moment on the shaft.
Known :
Mmax = 2652 Nm
Tmax = 1326 Nm
Km = 1,5
Kt = 1,5
(Value of Km and Kt based on the shaft suddenly applied load with minor shocks only).
The equivalent twisting moment (Te) can be calculated by following equation.

$$Te = \sqrt{(K_m \times M)^2 + (K_t \times T)^2}$$

$$Te = \sqrt{(1{,}5 \times 2652)^2 + (1{,}5 \times 1326)^2}$$

Te = 4447,54 Nm

Next, the value of safety factor can be determined by :

$$Te \quad = \frac{\pi}{16} \text{ x } \tau \text{ x } {d_o}^3$$

$$4447{,}54 = \frac{3{,}14}{16} \text{ x } \frac{0{,}75.850000000}{N} \text{ x } 0{,}05^3$$

$$N \quad = 3{,}52$$

The equivalent bending moment (Me) can be calculated by :

$$Me = \frac{1}{2}\left[K_m \text{ x } M + \sqrt{(K_m \text{ x } M)^2 + (K_t \text{ x } T)^2}\right]$$

$$Me = \frac{1}{2}\left[1{,}5 \text{ x } 2652 + \sqrt{(1{,}5 \text{ x } 2652)^2 + (1{,}5 \text{ x } 1326)^2}\right]$$

Me = 4212,77 Nm

Next, the value of safety factor can be determined by :

$$Me \quad = \frac{\pi}{32} \text{ x } \sigma \text{ x } {d_o}^3$$

$$4212{,}77 = \frac{3{,}14}{32} \text{ x } \frac{850000000}{N} \text{ x } 0{,}05^3$$

$$N \quad = 2{,}47$$

∴ Taking the minimum of the two value, so

$$N \quad = 2{,}47 \text{ say 3 Ans}$$

Based on the calculation step above, so the shaft that recommended to use, will be made by round bar (solid shaft) because the safety factor value of solid shaft greater than hollow shaft. Generally, the factor of safety value when designing shaft is 1,5 – 6 or N > 1,5.[8]

The next analysis will be done by simulation on solidwork software.

4.4.3 Support Component on Shaft

Type of bearing that used is the thrust ball bearings. It is chosen because it can be used for carrying thrust loads exclusively and at speeds below 2000 r.p.m. In this vertical axis turbine shaft, 6 bearings of cylindrical roller thrust bearing SKF 81110 TN were installed.

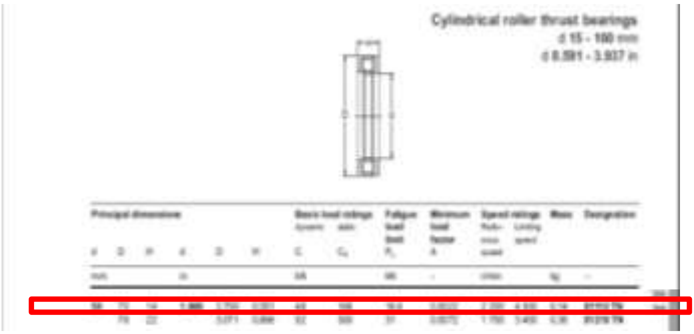


Figure 4.7 Bearing SKF 81110

Type of coupling that used is flexible coupling because considering the working conditions of vertical axis turbine shafts are under the sea and anticipate the vibration of whirling shaft so this coupling is selected to connect on each shaft, with Hub 1 (M1).

GAS-ST - standard jaw coupling «in steel»: introduction

- Made in steel fully turned with standard phosphating treatment.
- Several elastomer hardnesses available (page 71).
- High compensation of misalignments.
- Vibration dampening.
- Statically balanced.
- Modularity of the components, with different assembly versions.

ON REQUEST

- Conformity to ATEX directive possible.
- Specific treatments or version fully in stainless steel.
- Manufacturing made to length and customizations for specific needs.
- Connection to the Torque limiter's (safety coupling) range possible.

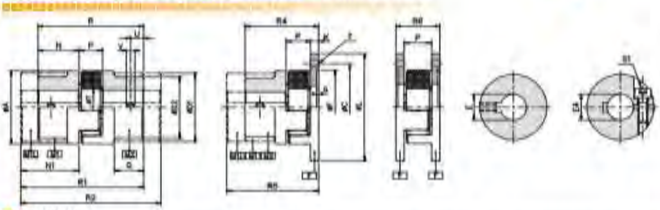
The coupling GAS/SG is an elastomeric coupling with compact dimensions composed of two hubs made in steel UNI EN10083/98, fully turned with one elastomer.
The hub's tooth profile is designed to allow the elastomeric element to work only by compression and not in shear, allowing for long life of the coupling in high reversal or load applications.

- **Hub 1 (M1)** : base hub for any kind of connection.
- **Long hub 1 (M1L)** : extended hub to connect long shafts.
- **Hub 2 (M2)** : hub with reduced external diameter for assembly in compact spaces.
- **Flangie (F)** : flange for connection shaft-flange.

Figure 4.8 Flexible Coupling

SKSSWE

GAS-ST - standard jaw coupling «in steel»: technical data



DIMENSIONS

Size	A	C	D1	D2	E H7 max M1	E H7 max M2	E4 H7 max M1	F H7	D	L	K	N	N1	P	Q	R	R1	R2	R4	R5	R6	T	U	V	Z
00 (19)	40	50	40	32	25	20	20	40	1,5	58	8	25	37	16	16,5	66	78	90	49	61	32	18	10	M5	n.5 x ø4,5
0 (24)	55	65	53	40	35	26	30	55	1,5	74	8	30	50	18	20	78	98	118	56	76	34	27	10	M5	n.5 x ø4,5
1 (28)	65	80	63	48	40	32	35	65	1,5	92	10	35	60	20	24	90	115	140	65	90	40	30	15	M8	n.6 x ø6,6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3 (42)	95	115	93	75	55	50	50	95	2	133	12	50	75	26	30	126	151	176	88	113	50	46	20	M8	n.6 x ø9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5 (55)	120	145	118	98	74	65	65	120	2	160	16	69	90	30	49	180	185	210	111	130	62	60	20	M10	n.8 x ø11
6 (65)	135	160	133	115	80	80	70	135	2	179	16	75	100	35	61	185	210	235	126	151	67	68	20	M10	n.10 x ø11
7 (75)	160	185	158	135	95	95	-	160	2,5	215	18	89	110	40	69	210	235	260	149	169	78	80	25	M10	n.10 x ø14
8 (90)	200	225	180	160	110	110	-	200	3	246	20	100	125	45	81	245	270	295	164	190	85	100	30	M12	n.12 x ø14
9 (100)	225	250	-	180	-	120	-	225	4	285	25	110	-	50	89	270	-	-	185	-	100	113	30	M12	n.12 x ø18
10 (110)	255	290	-	200	-	130	-	255	4	330	26	120	-	55	96	295	-	-	201	-	157	127	35	M16	n.12 x ø18

Figure 4.9 Dimension of Flexible Coupling

4.5 Finite Element Simulation

The simulation is carried out by entering paramater that have been known and calculated of the vertical axis turbine shaft into solidwork software and done by finite element method. The output of the simulation, it will know maximum stress, strain, safety factor, and deformation on the shaft.

Based on the calculation step above, the shaft that recommended to use, will be made by round bar (solid shaft) because the safety factor value of solid shaft greater than hollow shaft. The modelling and result of the simulation will be analyzed as following.

4.5.1 Modelling

The first step to have done before simulation process is making 3D Model of vertical axis turbine and input the parameter that have been known and calculated.

Vertical axis turbine shaft was arranged by a series of three shafts having a length respectively 3,3 m, 2 m and 2 m and connected by flexible coupling for each shaft. Figure 4.10 shows the 3D Model of vertical axis turbine shaft for TLP Platform. The list of component arranged on model is showed in Table 4.1.

Table 4.1 List of Component

No.	Component	Specification	Amount
1.	Turbine Shaft	Hollow Bar or Round Bar	3
2.	Coupling	Flexible coupling (GAS-ST - standard jaw coupling)	2
3.	Bearing	SKF 81110 TN Cylindrical roller thrust bearing	6

Figure 4.10 Vertical Axis Turbine 3D Model

4.5.2 Simulation Output

4.5.2.1 Stress

In the simulation results, the maximum stress on vertical axis turbine with round bar (solid shaft) of High Tensile Steel AISI 4140 material is equal to 144,06 Mpa. The maximum stress value is so far under the value of the tensile material amounted to 665 MPa.

Figure 4.11 Stress Output

Figure 4.8 shows the stress output of vertical axis turbine shaft. The maximum stress shown in shades of the red, while the minimum stress shown in blue color. Areas with moderate stress is in an area with color of yellow-green-and light blue.

Table 4. 2 Summary of Stress Output

Shaft Material	Type	High Tensile Steel AISI 4140		Medium Tensile Carbon Steel AISI 1045		Stainless Steel AISI 316	
		Hollow Bar	Round Bar	Hollow Bar	Round Bar	Hollow Bar	Round Bar
Min (MPa)	von Misses Stress	0 Node : 61935	0 Node : 57835	0 Node : 61935	0 Node : 57835	0 Node : 61935	0 Node : 57835
Max (MPa)	von Misses Stress	146,18 Node : 12693	144,06 Node : 12693	146,2 Node : 12693	144,06 Node : 12693	146,2 Node : 12693	144,05 Node : 12693

4.5.2.2 Strain

The simulation result for maximum strain occur on vertical axis turbine shaft is 0,000385895.

Figure 4.12 Strain Output

Figure 4.9 shows the strain output of vertical axis turbine shaft. The maximum strain shown in shades of the red, while the minimum strain shown in blue color. Areas with moderate strain is in an area with color of yellow-green-and light blue.

Table 4. 3 Summary of Strain Output

Shaft Material	Type	High Tensile Steel AISI 4140		Medium Tensile Carbon Steel AISI 1045		Stainless Steel AISI 316	
		Hollow Bar	Round Bar	Hollow Bar	Round Bar	Hollow Bar	Round Bar
Min	ESTRN	0 Element : 30505	0 Element : 29921	0 Element : 30505	0 Element : 29921	0 Element : 30505	0 Element : 29921
Max	ESTRN	0,000331898 Element : 15110	0,000385895 Element : 15110	0,000339993 Element : 15110	0,000395307 Element : 15110	0,000356134 Element : 15110	0,000414003 Element : 15110

4.5.2.3 Displacement

The simulation result for displacement maximum is 4,81578 mm, with deformation scale 175,333. The Figure 4.10 shows the form of deformation may occur.

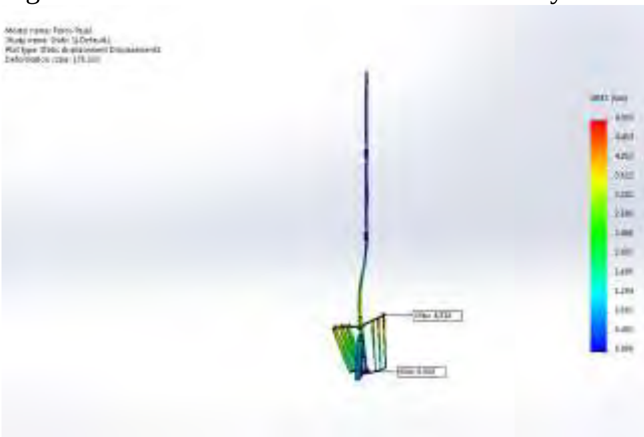


Figure 4.13 Displacement Output

Figure 4.10 shows the displacement output of vertical axis turbine shaft. The maximum displacement shown in shades of the red, while the minimum displacement shown in blue color. Areas with moderate displacement is in an area with color of yellow-green-and light blue.

Table 4.4 Summary of Displacement Output

Shaft Material	Type	High Tensile Steel AISI 4140		Medium Tensile Carbon Steel AISI 1045		Stainless Steel AISI 316	
		Hollow Bar	Round Bar	Hollow Bar	Round Bar	Hollow Bar	Round Bar
Min (mm)	URES	0 Node : 61935	0 Node : 57835	0 Node : 61935	0 Node : 57835	0 Node : 61935	0 Node : 57835
Max (mm)	URES	4,74554 Node : 4868	4,81578 Node : 4868	4,86128 Node : 4868	4,93323 Node : 4868	5,13822 Node : 4868	5,20919 Node : 4868

4.5.2.4 Factor of Safety

The simulation output of safety factor minimum for this vertical axis turbine shaft is 4,5 and while compare with the manual calculation is 3.

Figure 4.14 Safety Factor Output

Figure 4.11 shows the safety factor output of vertical axis turbine shaft. The minimum factor of safety is 4,5.

Table 4.5 Summary of Safety Factor

Shaft Material	Type	High Tensile Steel AISI 4140		Medium Tensile Carbon Steel AISI 1045		Stainless Steel AISI 316	
		Hollow Bar	Round Bar	Hollow Bar	Round Bar	Hollow Bar	Round Bar
Min	Auto	4,38892 Node : 12693	4,53479 Node : 12693	3,62568 Node : 12693	3,67897 Node : 12693	1,17868 Node : 12693	1,19655 Node : 12693
Max	Auto	1e+016 Node : 61935	1e+016 Node : 57835	1e+016 Node : 61935	1e+016 Node : 57835	1e+016 Node : 61935	1e+016 Node : 57835

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CHAPTER 5
CONCLUSION

5.1 Conclusion

According data analysis, the discussion, and simulation result using finite element method, so it can be concluded that.

1) The recommendation for specification of vertical axis turbine shaft that capable for 5 kW capacity on ocean current power plant.

   - The VAT shaft is arranged by a series of three shafts having a length 3,3 m, 2 m and 2 m and made by round bar (solid shaft) with 0,05 m diameter.
   - The material recommended to use is High Tensile Steel AISI 4140/ASTM A434 (A29) Grade 4140 that have 1% chromium-molybdenum medium hardenability with ultimate tensile strength (s_u) of the material 850 – 1000 MPa and the yield strength (s_y) 665 Mpa.

2) The maximum stress of the VAT Shaft with round bar of High Tensile Steel AISI 4140 is 144,06 MPa, maximum strain 0,000385895, maximum displacement 4,81578 mm with deformation scale 175,333 and the vertical axis turbine shaft can be operated with factor of safety 4,5 based on simulation, and based manual calculation its sfaety factor is 4 Ans.

5.2 Recommendation

Recommendation that can be given by the author for further research are :

1) The result of this final project can be used as a reference to the detail design of mechanical transmission system such as gearbox system.
2) Calculation and simulation of vibration that occur need to be done, in order to get the efficiency and more accurate.

ATTACHMENT 1

Catalogue of Rolling Bearings

Rolling bearings

SKF

Thrust Bearings

Thrust Ball Bearing

53210 U210 / M

1 — M

with seating washer — U210

Cylindrical Roller Thrust Bearing

81110 TN P5

1 — TN

2 — P5

Spherical Roller Thrust Bearing

29430 E

1 — E

1. Features

F	Machined steel or special cast iron cage, roller guided
J9	Internal design change to J cage
M	Machined brass cage, roller guided
P5	Dimensional and running accuracy to ISO tolerance class 5 (approximately ABEC 5)

1. Cage

Standard Reinforced Polyamide (TN)
Machined brass (M)
Steel (F)

2. Precision

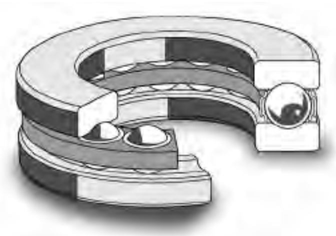
Normal, larger bearings can be offered in P5 (check for availability)

1. Features

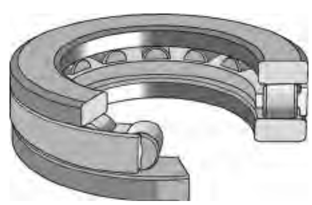
–	Machined brass cage (no symbol)
B	Pressed steel cage, no cage guide ring
E	Improved internal design
M	Machined brass cage, roller guided
RD	Spacer sleeve

Technical Features

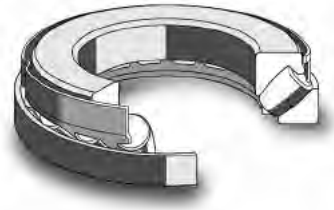
	Thrust Ball Bearings	Cylindrical Roller Thrust Bearings	Spherical Roller Thrust Bearings
Boundary Dimensions	Bearings with flat housing washers are in ccordance with ISO 104:2002. The bearings with sphered housing washers have dimensions in accordance with DIN 711:1988 and DIN 715:1987	ISO 104:2002	Boundary dimensions in accordance with ISO 104:2002. Tolerances in accordance with ISO 199:1997 but SKF height tolerance 50% tighter and SKF Explorer height 75% tighter.
Tolerances	Normal (ABEC 1)	Normal to ISO 199:1997	RBEC 1 (Normal)
Heat stabilization	250°F (125°C)	150°C (With Polyamide cages operate up to 120°C only)	392°F (200°C)
Misalignment	None - contact SKF	No misalignment between the shaft and housing, nor any errors of alignment between the support surfaces in the housing and on the shaft.	Normal load conditions/ permissible misalignment $F_a + 2.7 \times F_r < 0.05\ C_0$ series 29200 - 2 degrees series 29300 - 2.5 degrees series 29400 - 3 degrees
Cage Materials: Standard Optional	Pressed Steel Machined Brass (M)	Reinforced Polyamide TN9 Machined brass	heavier load conditions $F_a + 2.7 \times F_r > 0.05\ C_0$ 1.5 degrees for all series
Axial Load - max	Thrust bearing (see tables in General catalogue)		
Seals	Not available	Not available	Not available



Single Direction Thrust Ball Bearing (data tables on page 196)



Cylindrical Roller Thrust Bearing (data tables on page 205)



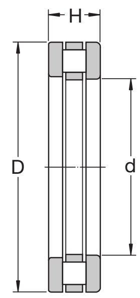
Spherical Roller Thrust Bearing (data tables on page 208)

Double Direction Thrust Ball Bearing (data tables on page 202)

Cylindrical roller thrust bearings

d **15 - 100** mm

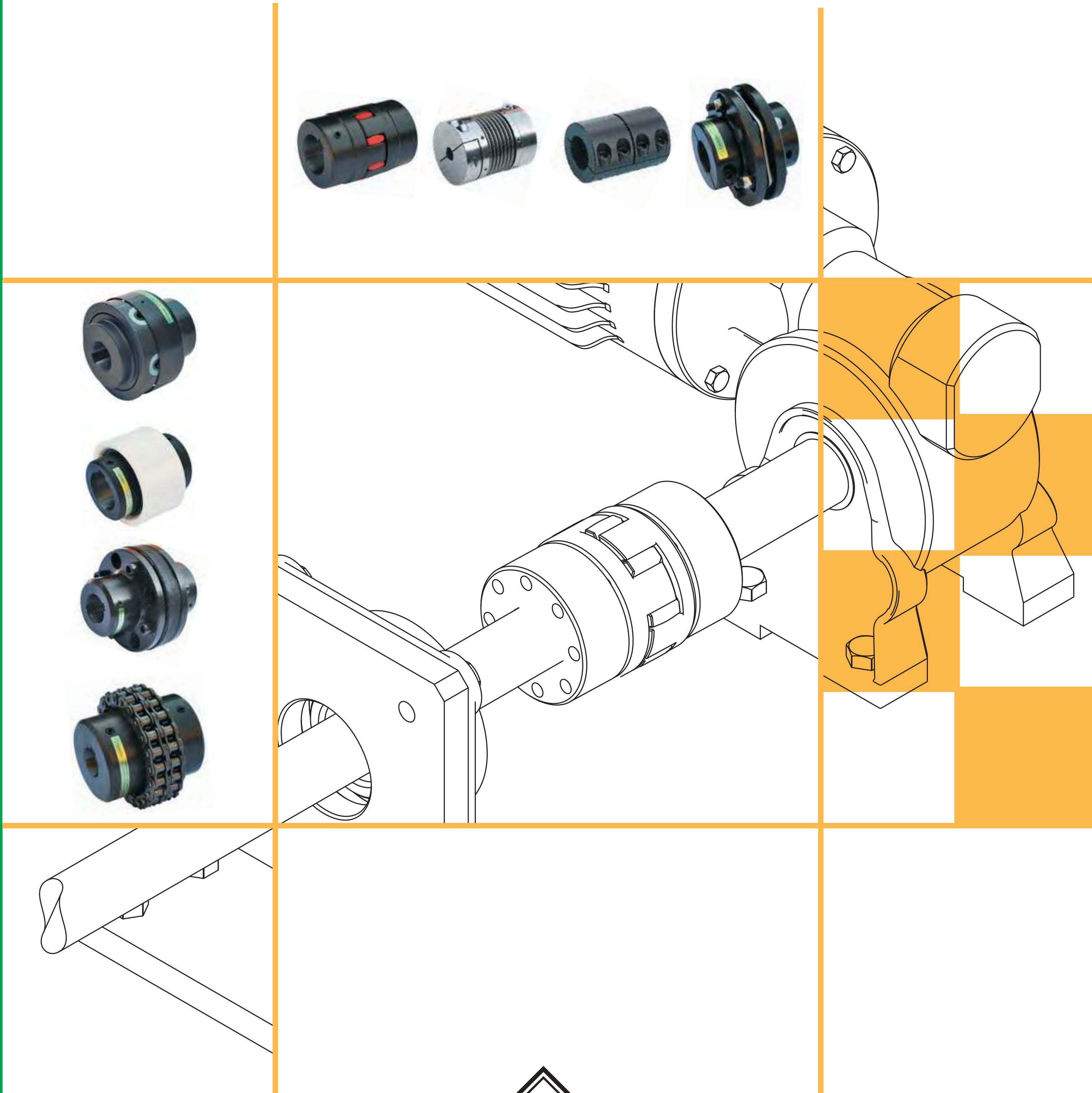
d **0.591 - 3.937** in



Principal dimensions						Basic load ratings dynamic	static	Fatigue load limit	Minimum load factor	Speed ratings Reference speed	Limiting speed	Mass	Designation
d	D	H	d	D	H	C	C_0	P_u	A				
mm			in			kN		kN	–	r/min		kg	–
15	28	9	**0.591**	1.102	0.354	11	27	2.45	0.000058	4 300	8 500	0.024	**81102 TN**
17	30	9	**0.669**	1.181	0.354	12	32	2.85	0.000079	4 300	8 500	0.027	**81103 TN**
20	35	10	**0.787**	1.378	0.394	19	48	4.65	0.00018	3 800	7 500	0.037	**81104 TN**
25	42	11	**0.984**	1.654	0.433	25	70	6.8	0.00039	3 200	6 300	0.053	**81105 TN**
30	47	11	**1.181**	1.850	0.433	27	78	7.65	0.00049	3 000	6 000	0.057	**81106 TN**
	52	16		2.047	0.630	50	134	13.4	0.0014	2 400	4 800	0.12	**81206 TN**
35	52	12	**1.378**	2.047	0.472	29	93	9.15	0.00069	2 800	5 600	0.073	**81107 TN**
	62	18		2.441	0.709	62	190	19.3	0.0029	2 000	4 000	0.2	**81207 TN**
40	60	13	**1.575**	2.362	0.512	43	137	13.7	0.0015	2 400	5 000	0.11	**81108 TN**
	68	19		2.677	0.748	83	255	26.5	0.0052	1 900	3 800	0.25	**81208 TN**
45	65	14	**1.772**	2.559	0.551	45	153	15.3	0.0019	2 200	4 500	0.13	**81109 TN**
	73	20		2.874	0.787	87	270	28	0.0058	1 800	3 600	0.29	**81209 TN**
50	70	14	**1.969**	2.756	0.551	48	166	16.6	0.0022	2 200	4 300	0.14	**81110 TN**
	78	22		3.071	0.866	92	300	31	0.0072	1 700	3 400	0.36	**81210 TN**
55	78	16	**2.165**	3.071	0.630	70	285	29	0.0065	1 900	3 800	0.22	**81111 TN**
	90	25		3.543	0.984	122	390	40	0.012	1 400	2 800	0.57	**81211 TN**
60	85	17	**2.362**	3.346	0.669	80	300	30.5	0.0072	1 800	3 600	0.27	**81112 TN**
	95	26		3.740	1.024	137	465	47.5	0.017	1 400	2 800	0.64	**81212 TN**
65	90	18	**2.559**	3.543	0.709	83	320	32.5	0.0082	1 700	3 400	0.31	**81113 TN**
	100	27		3.937	1.063	140	490	50	0.019	1 300	2 600	0.72	**81213 TN**
70	95	18	**2.756**	3.740	0.709	87	345	34.5	0.0095	1 600	3 200	0.33	**81114 TN**
	105	27		4.134	1.063	146	530	55	0.022	1 300	2 600	0.77	**81214 TN**
75	100	19	**2.953**	3.937	0.748	75	290	29	0.0067	1 600	3 200	0.39	**81115 TN**
	110	27		4.331	1.063	125	440	45	0.015	1 200	2 400	0.8	**81215 TN**
80	105	19	**3.150**	4.134	0.748	77	300	30.5	0.0072	1 500	3 000	0.4	**81116 TN**
	115	28		4.528	1.102	160	610	63	0.029	1 200	2 400	0.9	**81216 TN**
85	110	19	**3.346**	4.331	0.748	88	365	37.5	0.01	1 500	3 000	0.42	**81117 TN**
	125	31		4.921	1.220	153	550	57	0.024	1 100	2 200	1.25	**81217 TN**
90	120	22	**3.543**	4.724	0.866	104	415	42.5	0.013	1 300	2 600	0.62	**81118 TN**
	135	35		5.315	1.378	232	865	90	0.059	1 000	2 000	1.75	**81218 TN**
100	135	25	**3.937**	5.315	0.984	146	585	57	0.027	1 200	2 400	0.95	**81120 TN**
	150	38		5.906	1.496	224	830	81.5	0.055	900	1 800	2.2	**81220 TN**

ELASTOMERIC COUPLINGS - RIGID COUPLINGS
(BACKLASH FREE)

ATTACHMENT 2
Catalogue of Couplings



ComInTec®

GAS/SG - backlash free jaw coupling: introduction

- Made in steel fully turned with standard phosphating treatment.
- Several elastomer hardnesses available.
- High torsional ridigity.
- Electric insulation between the parts.
- Statically balanced.
- Version with integrated locking assemblies (GAS/SG/CCE).

ON REQUEST

- Conformity to Directive ATEX possible.
- Specific surface treatments or version fully in stainless steel, aluminium, possible.
- Manufacturing made to length and customizations for specific needs.
- Connection to ComInTec TORQUE LIMITERS range possible.

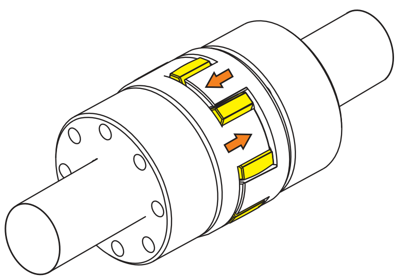
The coupling GAS/SG is an elastomeric coupling with compact dimensions composed of two hubs made in steel UNI EN10083/98, fully turned and one elastomeric element.

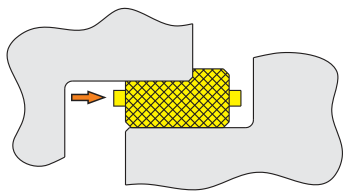
The hub's tooth profile is designed to allow the elastomeric element to work only by compression and not in shear, allowing for long life of the coupling in high reversal or load applications.

The presence of the elastomer assures:
- the possibility to absorb collisions and vibrations;
- to compensate for unavoidable misalignments between the shafts;
- silence during transmission;

DESCRIPTION OF THE ELASTOMERIC ELEMENT

The fundamental item of this coupling is the elastomeric element or elastomer, made in polyurethane and available in several hardness grades, for different uses and applications. The elastomer is manufactured to resist ageing, scoring, fatigue, hydrolysis and UV radiations, promoting long life operation. Also resisting main chemical agents, like ozone, oils, grease and hydrocarbons.
The elastomeric element becomes prestressed during the assembly between the relevant hub's teeth, in order to be able to transmit the motion without backlash, so torsionally rigid inside the prestressing load. The prestressed elastomer's surface is sufficiently wide to induce a low contact pressure on the tooth of the same elastomer, reducing the permanent deformations, promoting a long life.



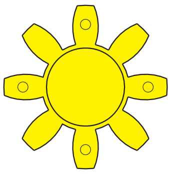


ATEX CONFORMITY

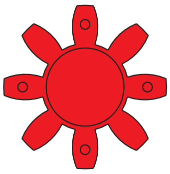
The GAS/SG coupling can be supplied in accordance to Directive 94/9/CE ATEX, which is relevant to protection apparatus and systems for use in potentially explosive spaces.
The dimensions of this coupling's version are not different from the standard version.
A mark relevant to the coupling's performances is printed on the hubs. It is necessary to consider planned tests, like described in the use and maintenance manual supplied together with each ATEX coupling.

The elastomeric elements used can be:

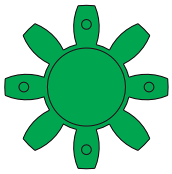
- red elastic element in polyurethane, 98 Shore-A : II 2 G D c T6 -20 ≤ Ta ≤ +60°C X U
- yellow elastic element in polyurethane, 92 Shore-A : II 2 G D c T5 -20 ≤ Ta ≤ +80°C X U



Elastomeric element **SG**
92 Sh-A



Elastomeric element **SG**
98 Sh-A



Elastomeric element **SG**
64 Sh-D

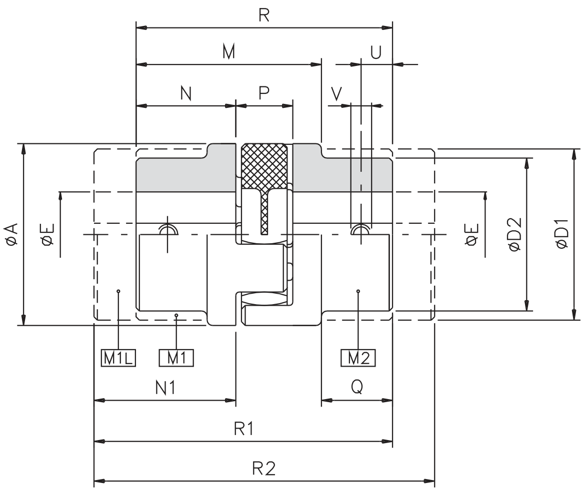
SG ELASTIC ELEMENT: TECHNICAL CHARACTERISTICS

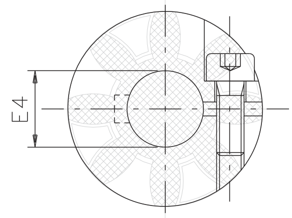
Hardness *[Shore]*	Material	Color	Permitted temperature *[°C]* Working	Permitted temperature *[°C]* For short period	Uses
92 Sh-A	Polyurethane	Yellow	-40 ÷ +90	-50 ÷ +120	- low and medium power - measurement and control system - common electric motors
98 Sh-A	Polyurethane	Red	-30 ÷ +90	-40 ÷ +120	- high transmission torque - actuators, screwjacks - servomotors, right angle gearboxes
64 Sh-D	Polyurethane	Green	-20 ÷ +110	-30 ÷ +120	- high torsional rigidity - tool machines - internal combustion motors

SG ELASTOMERIC ELEMENT: PERFORMANCE CHARACTERISTICS

Size	Hardness *[Sh]*	Torque *[Nm]*		Misalignments			Rigidity		
		Nom	Max	angular α *[°]*	axial X *[mm]*	radial K *[mm]*	torsional R_T *[Nm/rad •10³]*	axial R_A *[N/mm]*	radial R_R *[N/mm]*
01 (14/16)	**92 Sh-A**	7,5	15	1°	1	0,14	115	340	330
	98 Sh-A	12,5	25	0° 54'		0,09	170	510	650
	64 Sh-D	16	32	0° 48'		0,06	235	700	855
00 (19/24)	**92 Sh-A**	10	20	1°	1,2	0,10	680	1900	1200
	98 Sh-A	17	34	0° 54'		0,06	980	2300	2000
	64 Sh-D	21	42	0° 48'		0,04	1400	4280	2900
0 (24/28)	**92 Sh-A**	35	70	1°	1,4	0,14	1600	4410	1560
	98 Sh-A	60	120	0° 54'		0,10	2350	6300	2620
	64 Sh-D	75	150	0° 48'		0,07	3050	9600	3710
1 (28/38)	**92 Sh-A**	95	190	1°	1,5	0,15	2410	7060	2020
	98 Sh-A	160	320	0° 54'		0,11	3620	10900	3490
	64 Sh-D	200	400	0° 48'		0,08	4500	14500	4500
2 (38/45)	**92 Sh-A**	190	380	1°	1,8	0,16	5250	11950	2400
	98 Sh-A	325	650	0° 54'		0,12	7850	21850	4650
	64 Sh-D	405	810	0° 48'		0,09	9920	33600	6380
3 (42/55)	**92 Sh-A**	265	530	1°	2	0,18	6800	14700	2450
	98 Sh-A	450	900	0° 54'		0,15	18600	47500	5760
	64 Sh-D	560	1120	0° 48'		0,10	26400	71300	7570
4 (48/60)	**92 Sh-A**	310	620	1°	2,1	0,22	7800	18000	2850
	98 Sh-A	525	1050	0° 54'		0,16	20400	50600	6400
	64 Sh-D	655	1310	0° 48'		0,11	32400	96250	8900
5 (55/70)	**98 Sh-A**	685	1370	0° 54'	2,2	0,17	24200	61500	7150
6 (65/75)	**98 Sh-A**	1040	2080	0° 54'	2,6	0,18	38000	96500	6450

GAS/SG - backlash free jaw coupling: technical data





Clamp locking
(on request)

DIMENSIONS

Size	A	D1	D2	E H7 max	E4 H7 max	M	N	P	Q	R	T	U	V	N1	R1	R2
01 (14/16)	30	30	-	16	15	-	11	12	-	35	10	5	M4	18,5	42,5	50
00 (19/24)	40	40	32	25	20	-	25	16	16,5	66	18	10	M5	37	78	90
0 (24/28)	55	53	40	35	30	54	30	18	18,5	78	27	10	M5	50	98	118
1 (28/38)	65	63	48	40	35	62	35	20	24	90	30	15	M8	60	115	140
2 (38/45)	80	78	66	48	45	77	45	24	33	114	38	15	M8	70	139	164
3 (42/55)	95	93	75	55	50	86	50	26	38	126	46	20	M8	75	151	176
4 (48/60)	105	103	85	62	60	95	56	28	45	140	51	20	M8	80	164	188
5 (55/70)	120	118	98	74	65	108	65	30	49	160	60	20	M10	90	185	210
6 (65/75)	135	133	115	80	70	124	75	35	61	185	68	20	M10	100	210	235

TECHNICAL CHARACTERISTICS

Size	Torque *[Nm]*	Weight *[Kg]*			Inertia *[Kgm²]*			Max speed *[Rpm]*	Clamp locking	
		M1	M2	Element	M1	M2	Element		Screw	Tightening torque *[Nm]*
01 (14/16)	See page 17	0,06	-	0,005	0,00001	-	0,0000005	25000	M4	3,1
00 (19/24)		0,2	0,2	0,009	0,00005	0,00003	0,000003	19000	M5	6,2
0 (24/28)		0,4	0,3	0,020	0,00020	0,00010	0,00001	13500	M6	10,5
1 (28/38)		0,7	0,5	0,030	0,00042	0,00022	0,00002	11800	M8	25
2 (38/45)		1,3	1,1	0,060	0,00131	0,00089	0,00005	9500	M8	25
3 (42/55)		1,9	1,8	0,980	0,00292	0,00232	0,00010	8000	M10	69
4 (48/60)		2,8	2,4	0,105	0,00483	0,00383	0,00020	7100	M12	120
5 (55/70)		4,0	3,8	0,150	0,00825	0,00740	0,00030	6300	M12	120
6 (65/75)		5,9	4,6	0,200	0,01682	0,01087	0,00050	5600	M12	120

TORQUE PERMISSIBLE WITH CLAMP LOCKING

Size	*Torque transmitted [Nm] according to the ø finished bore [mm]*																											
	6	**8**	**10**	**11**	**12**	**14**	**15**	**16**	**18**	**19**	**20**	**22**	**24**	**25**	**28**	**30**	**32**	**35**	**38**	**40**	**42**	**45**	**48**	**50**	**55**	**60**	**65**	**70**
01 (14/16)	6	7	8	8	9	10	10																					
00 (19/24)			21	21	22	22	23	23	24	25	25																	
0 (24/28)					43	44	44	45	46	47	47	49	50	51	53	54												
1 (28/38)									90	91	92	95	97	98	102	104	107	110										
2 (38/45)											109	111	113	114	118	120	123	126	130	133	135	139						
3 (42/55)														260	267	272	276	284	291	296	301	308	316	321				
4 (48/60)																			449	456	463	474	484	491	509	528		
5 (55/70)																					508	519	530	537	555	573	591	
6 (65/75)																						564	575	582	600	618	636	654

NOTE

Technical characteristics: the weights refer to the coupling with pilot bore; inertias refer to the coupling with maximum bore.

ComInTec®

ATTACHMENT 3

Material 1 - AISI 4140 High Tensile Steel

Interlloy ENGINEERING STEELS + ALLOYS

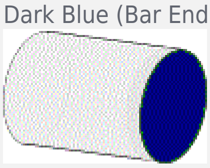
4140 HIGH TENSILE STEEL

4140 is a 1% chromium - molybdenum medium hardenability general purpose high tensile steel - generally supplied hardened and tempered in the tensile range of 850 - 1000 Mpa (condition T).4140 is now available with improved machinability, which greatly increases feeds and/or speeds, while also extending tool life without adversley affecting mechanical properties.

Pre hardened and tempered 4140 can be further surface hardened by flame or induction hardening and by nitriding.

4140 is used extensively in most industry sectors for a wide range of applications such as:

Adapters, Arbors, Axle Shafts, Bolts, Crankshafts, Connection Rods, Chuck Bodies, Collets, Conveyor Pins & Rolls, Ejector Pins, Forks, Gears, Guide Rods, Hydraulic Shafts & Parts,Lathe Spindles, Logging Parts, Milling Spindles, Motor Shafts, Nuts, Pinch Bars, Pins Various, Pinions, Pump Shafts, Rams, Sockets, Spindles, Sprockets, Studs, Tool Holders, Torsion Bars, Worms etc..

Colour Code	Stocked Sizes	
Dark Blue (Bar End) 	Rounds	8 mm to 690 mm Diameter
	Hexagons	19.05 mm to 65 mm A/F
	Hollow Bar	63 mm to 250 mm OD
	Square	32 mm to 130 mm
	Bar Finish	
	Peeled, Cold Drawn, Turned and Polished, Centreless Ground. or Hot Rolled.	

Related Specifications	
Australia	AS 1444-1996-4140
Germany	DIN 17212 W.Nr 1.7223 Type 41CrMo4 DIN 17200-1654 W.Nr 1.7225 Type 42CrMo4 DIN 17200 W.Nr 1.7227 Type 42CrMoS4
Great Britain	BS970-1955 EN19A BS970 Part 3:1991 709M40
International	ISO 683/II Type 3 ISO 683/IV Type 3a ISO 683/IV Type 3b
Japan	JIS G 4103 SNCM4 JIS G 4105 SCM4 JIS G 4105 SCM440
USA	AISI 4140 ASTM A29/A29M-91 4140 ASTM A322 4140 ASTM A331 4140 (Cold Finish) SAE 4140

Chemical Composition (Base Material)		
	Min. %	**Max %**
Carbon	0.36	0.44
Silicon	0.10	0.40
Manganese	0.65	1.10
Chromium	0.75	1.20
Molybdenum	0.15	0.35

Phosphorous	0	0.04
Sulphur	0	0.04

Mechanical Property Requirements for Steels in the Heat-Treated Condition for Turned, Peeled or Ground Finish to AS1444-1996 4140 and BS970 Part 3-1991 709M40

Mechanical Property Designation		R	S	S	*T	U	V	W
Limited Ruling Section mm		250	250	150	100	63	30	20
Tensile Strength Mpa	Min	700	770	770	850	930	1000	1080
	Max	850	930	930	1000	1080	1150	1230
0.2% Proof Stress Mpa	Min	480	540	570	655	740	835	925
Elongation on $5.65\sqrt{S_0}$ %	Min	15	13	15	13	12	12	12
Izod Impact J	Min	34	27	54	54	47	47	40
Charpy Impact J	Min	28	22	50	50	42	42	35
Hardness Brinell HB	Min	201	233	233	248	269	293	311
	Max	255	277	277	302	331	352	375

*Material stocked generally in condition T
Check test certificate if critical for end use.

Mechanical Property Requirements for Steels Heat-Treated, and then Cold Finished to AS 1444 - 1996, and BS 970 Part 3 - 1991 709 M40

Mechanical Property Designation		R	S	T	U	V
Limited Ruling Section		63	63	63	63	63
Tensile Strength Mpa	Min	700	770	850	930	1000
	Max	850	930	1000	1080	1150
0.20% Proof Stress Mpa	Min	525	585	680	755	850
Elongation on $5.65\sqrt{S_0}$ %	Min	12	11	9	9	9
Hardness Brinell HB	Min	201	223	248	269	293
	Max	255	277	302	331	352

*Material stocked generally in condition T
Check test certificate if critical for end use.

Forging

Heat to 1150 ℃ - 1200 ℃ maximum, hold until temperature is uniform throughout the section.
Do not forge below 850 ℃.Following forging operation the work piece should be cooled as slowly as possible.

Heat Treatment

Annealing

Heat to 800 ℃ - 850 ℃, hold until temperature is uniform throughout the section and cool in furnace.

Flame or Induction Hardening

4140 hardened and tempered bar can be further surface hardened by either the flame or induction hardening methods resulting in a case hardness in excess of Rc 50.Parts should be heated as quickly as possible to the austenitic temperature range (840 C - 870 C) and "required case depth followed by an immediate oil or water quench, depending upon hardness required, workpiece" size/shape and quenching arrangements.
Following quenching to hand warm, most components should be tempered between 150 C - 200 C to remove quenching stresses in the case. This will have little effect on case hardness and will reduce the risk of grinding cracks.

Hardening

Heat to 840 ℃ - 875 ℃, hold until temperature is uniform throughout the section, soak for 10 - 15 minutes per 25 mm section, and quench in oil, water, or polymer as required.*Temper immediately while still hand warm.

Nitriding

4140 hardened and tempered bar can also be successfully nitrided, giving a surface hardness of up to Rc 60. Nitriding is carried out at 490 ℃ - 530 ℃, followed by slow cooling (no quench) reducing the problem of distortion. Parts can therefore be machined to near final size, leaving a grinding allowance only. The tensile strength of the core is usually not affected since the nitriding temperature range is generally below the original tempering temperature employed.
Normalizing
Heat to 870 ℃ - 900 ℃, hold until temperature is uniform throughout the section, soak for 10 - 15 minutes and cool in still air.
Stress Relieving
Heat to 680 ℃ - 700 ℃, hold until temperature is uniform throughout the section, soak for 1 hour per 25 mm section, and cool in still air.
Tempering
Re-heat to 550 ℃ - 700 ℃ as required, hold until temperature is uniform throughout the section, soak for 1 hour per 25 mm of section, and cool in still air.
Notes on Heat Treatment
Heating temperatures, rate of heating and soaking times will vary due to factors such as work piece size/shape also furnace type employed, quenching medium and work piece transfer facilities etc..Please consult your heat treater for best results.
Machining
4140 in the hardened and tempered as supplied condition has good to very good machinability and operations such as sawing, turning, drilling, broaching, hobbing, milling and tapping can be carried out satisfactoraly using machine manufacturers recommendations for suitable tool type - feeds and speeds.
Welding
Welding of 4140 in the hardened and tempered condition (as normally supplied), is not recommended and should be avoided if at all possible, as the mechanical properties will be altered within the weld heat affected zone. It is preferred that welding be carried out on 4140 while in the annealed condition, and that the work piece, immediately on cooling to hand warm, is then stress relieved at 595 ℃ - 620 ℃ prior to hardening and tempering.If welding in the hardened and tempered condition is really necessary, then the work piece, immediately on cooling to hand warm, should be stress relieved at 15 ℃ below the original tempering temperature.
Welding Procedure
Welding of 4140 in whatever condition should always be carried out using low hydrogen electrodes - please consult your welding consumables supplier.

Suggested pre-heat temperature

Section	25mm	40mm	50mm	75mm	150mm +
℃	370	400	425	455	510

Post Welding

Maximum cooling rate 95 ℃ per hour down to 95 ℃, follow by cooling in still air. N.B. No draught.It is recommended that the work piece if possible is wrapped in an heat resistant blanket or buried in sand etc..

ATTACHMENT 4

Material 2 - AISI 1045 Medium Tensile Carbon Steel

1045 MEDIUM TENSILE CARBON STEEL BAR

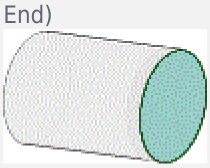
1045 is a medium tensile low hardenability carbon steel generally supplied in the black hot rolled or occasionally in the normalised condition, with a typical tensile strength range 570 - 700 Mpa and Brinell hardness range 170 - 210 in either condition.Characterised by fairly good strength and impact properties, plus good machinability and reasonable weldability in the hot rolled or normalised condition.

1045 has a low through hardening capability with sections up to around 60mm only generally recommended as suitable for through hardening and tempering. It can however be successfully flame or induction hardened in the as rolled or normalised condition resulting in surface hardnesses of up to Rc 54 - Rc 60 depending upon quenching medium employed, type of set up, section size etc. Core strengths will remain as supplied.

It does not however respond satisfactorily to nitriding due to a lack of suitable alloying elements.

1045 is used extensively by all industry sectors for applications requiring more strength and wear resistance than the low carbon mild steels can provide and the higher strength of the low alloy high tensile steels is not necessary, plus those applications requiring flame or induction hardening.

Typical applications are: Axles Various, Bolts, Connecting Rods, Hydraulic Clamps and Rams, Pins Various, Rolls Various, Studs, Shafts, Spindles etc.

Colour Code	Stocked Sizes	
Serpentine (Bar End) 	Rounds	16 mm - 690 mm Dia
	Squares	25 mm - 100mm

Related Specifications	
Australia	AS 1442 - 1992 1045
Germany	W.Nr 1.0503 C45 W.Nr 1.1191 CK45
Great Britain	BS970 - Part 3 - 1991 080A47 BS970 - Part 1 - 1972 080M46 BS970 - 1955 EN43B
Japan	JIS G 4051 S45C
USA	AISI C1045 ASTM A29/A29M - 91 1045 SAE 1045 UNS G 10450

Chemical Composition		
	Min. %	**Max. %**
Carbon	0.43	0.50
Silicon	0.10	0.35
Manganese	0.60	0.90

Typical Mechanical Properties - Hot Rolled Condition	
Tensile Strength Mpa	570 - 700
Yield Strength Mpa	300 - 450
Elongation in 50mm %	14 - 30

Hardness Brinell HB	170 - 210			
Typical Mechanical Properties - Normalised Condition				
Tensile Strength Mpa		640		
Yield Strength Mpa		410		
Elongation in 50mm %		22		
Impact Izod J		54		
Hardness	HB	187		
	Rc	10		
*Material stocked generally in the hot rolled condition but can occasionally be in the normalised condition.NB. Check the mill certificate if critical for end use.				
Typical Mechanical Properties - Hardened by Water Quench at 820 ℃ - 850 ℃ or oil quench at 830 ℃ - 860℃ and Tempered Between 540 ℃ - 680 ℃				
Section Size mm		up to 16mm	17 - 40mm	41 - 100mm
Tensile Strength Mpa	Min	700	650	630
	Max	850	800	780
Yield Strength Mpa	Min	500	430	370
Elongation in 50mm %	Min	14	16	17
Impact Charpy J	Average	30	30	30
Hardness HB	Min	210	195	185
	Max	245	235	230

Forging

Pre heat to 750 ℃ - 800 ℃, then continue heating to 1100 ℃ - 1200 ℃ maximum, hold until temperature is uniform throughout the section and commence forging immediately.Do not forge below 850 ℃
Finished forgings may be air cooled.

Heat Treatment

Annealing

Heat to 800 ℃ - 850 ℃ hold until temperature is uniform throughout the section, and cool in furnace.

Flame or Induction Harderning

Heat as quickly as possible to the austenitic temperature range (820 ℃ - 860 ℃) and required case depth followed by an immediate water or oil quench, depending upon hardness required, workpiece size/shape and quenching arrangements.The black hot rolled/normalised surface will first require to be machined sufficiently to remove any de carburised layer, otherwise less than satisfactory results will be obtained.
Following quenching to hand warm, most components should be tempered at 150 ℃ - 200 ℃ to remove quenching stresses in the case. This will have little effect on case hardness.

Hardening

Heat to 820 ℃ - 850 ℃ hold until temperature is uniform throughout the section, soak for 10 - 15 minutes per 25mm of section, and quench in water or brine.
or:
Heat to 830 ℃ - 860 ℃ soak as above and quench in oil.Temper immediately while still hand warm.

Normalizing

Heat to 870 ℃ - 920 ℃ hold until temperature is uniform throughout the section, soak for 10 - 15 minutes.Cool in still air.

Stress Relieving

Heat to 550 ℃ - 660 ℃ hold until temperature is uniform throughout the section, soak for 1 hour per 25mm of section, and cool in still air.

Tempering

Re heat to 400 ℃ - 650 ℃ as required, hold until temperature is uniform throughout the section, soak for 1 hour per 25mm of section, and cool in still air.

Notes on Heat Treatment

Heating temperatures, rate of heating, cooling and soaking times will vary due to factors such as work piece size/shape, also furnace type employed, quenching medium and work piece transfer facilities etc.Please consult your heat treater for best results.
Machining
1045 in the hot rolled and normalised condition has very good machinability and all operations such as sawing, turning, drilling, broaching, milling and tapping etc. can be carried out satisfactorily using machine manufacturers recommendations for suitable tool type, feeds and speeds.
Welding
1045 is readily weldable in the as rolled and normalised condition providing the correct procedure is employed.Following welding the work piece immediately upon cooling to hand warm should be stress relieved at 550 °C - 660 °C if possible. NB. Welding in the hardened and tempered, flame or induction hardened condition is not recommended.
Welding Procedure
Welding of 1045 should always be carried out using low hydrogen electrodes.Please consult your welding consumables supplier.
Suggested Pre-heat Temperature

Section	25mm	50mm	75mm	150mm +
°C	100	140	200	300

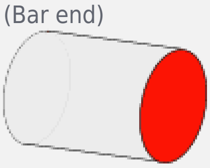
Post Welding
Cool as slowly as possible in dry lime, sand etc.

ATTACHMENT 5
Material 3 - AISI 316 Stainless Steel

Interlloy™ ENGINEERING STEELS + ALLOYS

316 AUSTENITIC STAINLESS STEEL BAR

316 is a chromium-nickel-molybdenum austenitic stainless steel with good strength and excellent corrosion resistance, as supplied in the annealed condition with a typical brinell hardness of 175.Characterised by high corrosion resistance in marine and industrial atmospheres, it exhibits excellent resistance to chloride attack and against complex suphur compounds employed in the pulp and paper processing industries. The addition of 2% to 3% of molybdenum increases its resistance to pitting corrosion and improves its creep resistance at elevated temperatures. Also it displays good oxidation resistance at elevated temperatures and has excellent weldability.
316 cannot be hardened by thermal treatment, but strength and hardness can be increased substantially by cold working, with susequent reduction in ductility.
It is now available with improved machinability (by calcium injection treatment), which has little effect on corrosion resistance and weldability while greatly increasing feeds and/or speeds, plus extending tool life.
It is used extensively by the Marine, Chemical, Petrochemical, Pulp and Paper, Textile, Transport, Manufacturing and allied industries.
Typical uses are:
Architectural Components, Textile Equipment, Pulp and Paper Processing Equipment, Marine Equipment and Fittings, Photographic Equipment and X-Ray Equipment etc..
Material non magnetic in the annealed condition, but can become mildly magnetic following heavy cold working. Annealing is required to rectify if necessary.
N.B. Optimum corrosion resistance is achieved in the annealed condition.

Colour Code	Stocked Sizes	
Red (Bar end) 	Rounds	3.18 mm to 325 mm diameter.
	Hexagons	7.94 mm to 63.5 mm A/F
	Squares	6.35 mm to 50 mm A/F
	Hollow Bar	32 mm - 250 mm OD
	Bar Finish	
	Peeled, Cold Drawn Turned and Polished, and Centreless Ground.	

Related Specifications	
Australia	AS 2837-1986-316
Germany	W.Nr 1.4401 X5CrNiMo17 12 2 W.Nr 1.4436 X5CrNiMo 17 13 3
Great Britain	Bs970 Part 3 1991 316S31/316S33 Bs970 1955 EN58J
Japan	JIS G4303 SuS 316
USA	ASTM A276-98b 316 SAE 30316 AISI 316 UNS S31600

Chemical Composition

	Min. %	**Max %**
Carbon	0	0.08
Silicon	0	1.00
Manganese	0	2.00
Nickel	10.00	14.00

Chromium	16.00	18.00
Molybdenum	2.00	3.00
Nitrogen	0	0.10
Phosphorous	0	0.045
Sulphur	0	0.03

Mechanical Property Requirements - Annealed to ASTM A276-98b 316

Finish	Hot Finish	Cold Finish	
Dia or Thickness mm	All	Up to 12.7	Over 12.7
Temsile Strength Mpa Min.	515	620	515
Yield Strength Mpa Min.	205	310	205
Elongation in 50mm % Min.	40	30	30

Typical Mechanical Properties At Room Temperature - Annealed

Finish		Cold Drawn	Other
Tensile Strength Mpa		680	590
Yield Strength Mpa		500	280
Elongation in 50mm %		42	55
Impact Charpy V J		190	180
Hardness	HB	195	155
	Rc	13	

Elevated Temperature Properties

316 displays good oxidation resistance in continuous service up to 930 °C, and in intermittent service up to 870 °C.NB. Continuous service however between 430 °C and 870 °C is not recommended, nor is slow cooling through this range due to the problem of intergranular corrosion. 316L (low carbon type) can be employed to overcome this problem.
Mechanical properties are reduced as temperature increases.

Typical Mechanical Properties - Annealed at Elevated Temperatures

Temperature °C	20	550	600	650	700	750	850
Short - Time Tensile Tests Tensile Strength Mpa	590	500	480	460	450	355	260
Creep Tests Stress for 1% Creep in 10,000 hours Mpa		170	120	90	55	35	20

Low Temperature Properties

316 has excellent low temperature properties, with increased tensile and yield strength without loss of toughness in the annealed condition.

Typical Mechanical Properties - Annealed at Zero and Sub-Zero Temperatures

Temperature °C	0	-70	-130	-180	-240
Tensile Strengt Mpa	650	750	990	1200	1450
Yield Strength Mpa	310	350	470	530	600
Elongation in 50mm %	67	65	62	60	56
Impact Charpy V J	190	190	183	183	183

The combination of high strength and toughness at low temperatures allows this grade to be used in extremely cold climates or high altitudes, also for storage of liquified gasses etc. at very low temperatures.N.B. 316 even when cold worked will still have good high strength and ductility at sub-zero temperatures.

Cold Bending

316 has good cold bending properties and cold bending can generally be carried out without too much difficulty, after cold working it may be mildly magnetic. Annealing is recommended following cold working, causing more than 15% deformation.

Hot Bending

Hot bending should be performed at 950 °C - 1100 °C, followed by annealing to restore optimum corrosion resistance.

Corrosion Resistance
General Corrosion
316 has better resistance to general corrosion in most media than 310, 304, 321, 302 and 303 grades.
Stress Corrosion Cracking
316 has a better resistance to stress corrosion cracking in chloride solutions than 302 or 304 grades, however it can also fail if subjected to high stresses in an environment conducive to stress corrosion.
Pitting Corrosion / Crevice Corrosion
316 has higher resistance to both pitting and crevice corrosion than the non molybdenum bearing grades such as 304, 321, 310 and 303 etc..
Intergranular Corrosion
316 has better resistance to intergranular corrosion than the higher carbon grades 303, 310 or 302 but not as good as the low carbon grades 316L and 304L, or the titanium stabilised grade 321.N.B. It is most important that oxygen is always allowed to circulate freely on all stainless steel surfaces to ensure that a chrome oxide film is always present to protect it. If this is not the case, rusting will occur as with other types of non stainless steel. For optimum corrosive resistance surfaces must be free of scale and foreign particles. Finished parts should be passivated.
Forging
Heat uniformly to 1150 ℃ - 1200 ℃, hold until temperature is uniform throughout the section.Do not forge below 900 ℃ Finished forgings should be air cooled. Finally forgings will require to be annealed in order to obtain optimum corrosion resistance.
Heat Treatment
Annealing
Heat to 1020 ℃ - 1100 ℃, hold until temperature is uniform throughout the section. *Soak as required. Quench in water to obtain optimum corrosion resistance.*Actual soaking time should be long enough to ensure that the part is heated thoroughly throughout its section to the required temperature, 30 minutes per 25 mm of section may be used as a guide. Please consult your heat treater for best results.
Machining
316 improved machinability is slightly more difficult to machine than improved machinability 304 grade. More difficult to machine than 303 free machining grade and most of the 400 series stainless steels. It has a typical machinability rating around 50% - 55% of free machining (S1214) mild steel.Due to the high work hardening rate of this grade, cutting or drilling tools etc. must be kept sharp at all times and not cause unnecessary work hardening of the surface etc.. All machining should be carried out as per machine maunfacturers recommendations for suitable tool type, feeds and speeds.
Welding
316 is readily weldable by shielded fusion and resistance welding processes, followed by air cooling giving good toughness.Oxcyacetylene welding is not recommended due to possible carbon pick up in the weld area. Small sections may be welded without loss of corrosion resistance due to intergranular carbide precipitation, but larger sections, or for service in the more extreme conditions post weld annealing is recommended.
Welding Procedure
Welding should be carried out using 316, 316L or *similar electrodes or rods (depending upon application). No pre heat or post heat is generally required.*Please consult your welding consumables supplier.

ATTACHMENT 6

Simulation Report of Hollow Shaft Material 1

Simulation of Hollow Shaft - Material 1 (High Tensile AISI 4140)

Date: 27 Juli 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

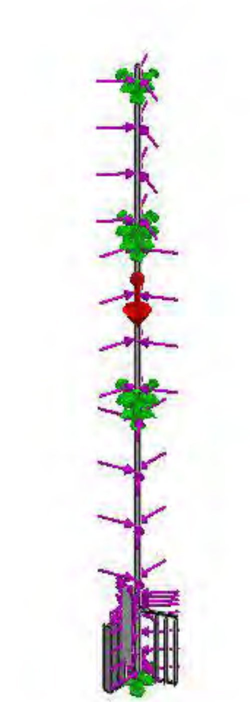
Table of Contents

Description

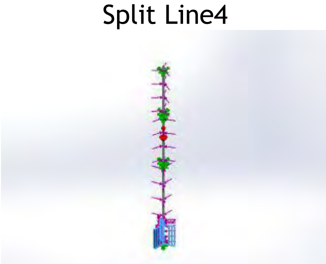
No Data

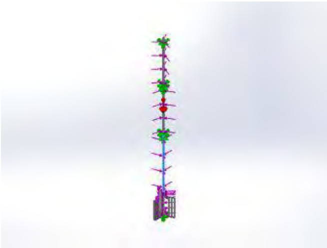
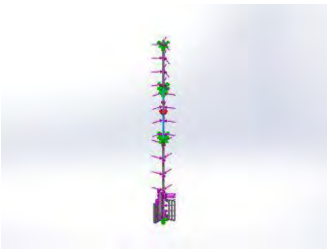
Assumptions

Model Information



Model name: Poros Hollow Material 1
Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Split Line4 	Solid Body	**Mass:92.5843 kg** **Volume:0.0117894 m^3** **Density:7853.17 kg/m^3** **Weight:907.326 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\NACA 0018.sldprt** Jun 21 15:07:01 2016

Boss-Extrude1 	Solid Body	**Mass:18.2038 kg** **Volume:0.00231895 m^3** **Density:7850 kg/m^3** **Weight:178.397 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\poros 1.SLDPRT** Jun 27 15:07:39 2016
Boss-Extrude1 	Solid Body	**Mass:15.7217 kg** **Volume:0.00200277 m^3** **Density:7850 kg/m^3** **Weight:154.073 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\poros 2.SLDPRT** Jun 21 15:07:01 2016
Body-Move/Copy1	Solid Body	**Mass:15.7217 kg** **Volume:0.00200277 m^3** **Density:7850 kg/m^3** **Weight:154.073 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\poros 3.SLDPRT** Jun 21 15:07:01 2016
Revolve1 	Solid Body	**Mass:3.9389 kg** **Volume:0.00050177 m^3** **Density:7850 kg/m^3** **Weight:38.6012 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016
Revolve1 	Solid Body	**Mass:3.9389 kg** **Volume:0.00050177 m^3** **Density:7850 kg/m^3** **Weight:38.6012 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016

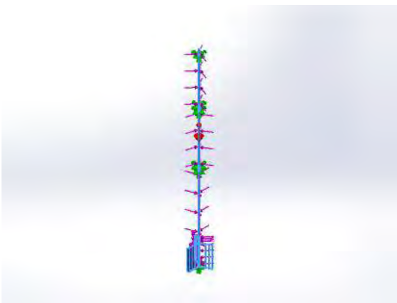
Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Mixed Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SolidWorks document (D:\Dhaifina Suci Soraya\Poros Hollow\Simulasi\Material 1 AISI 4140 - Hollow)

Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

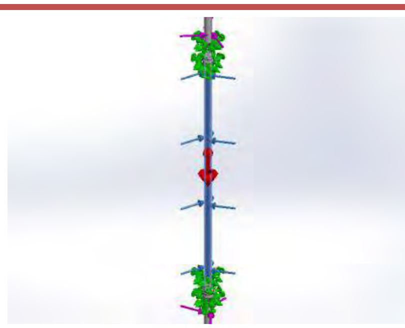
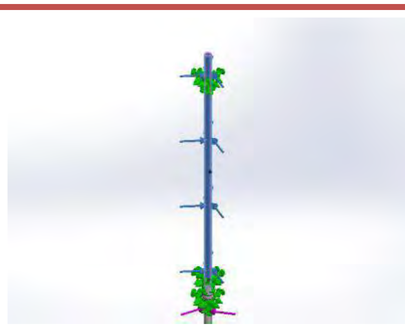
Model Reference	Properties	Components
	**Name:** AISI 4140 **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max Normal Stress **Yield strength:** 6.65e+008 N/m^2 **Tensile strength:** 8.5e+008 N/m^2 **Compressive strength:** 8.5e+008 N/m^2 **Elastic modulus:** 2.1e+011 N/m^2 **Poisson's ratio:** 0.29 **Mass density:** 7850 kg/m^3	SolidBody 1(Split Line4)(NACA 0018-1), SolidBody 1(Boss-Extrude1)(poros 1-1), SolidBody 1(Boss-Extrude1)(poros 2-1), SolidBody 1(Body-Move/Copy1)(poros 3-1), SolidBody 1(Revolve1)(soupling-1), SolidBody 1(Revolve1)(soupling-2), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-11), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-12), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-13), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-14), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-15), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-16)
Curve Data:N/A		

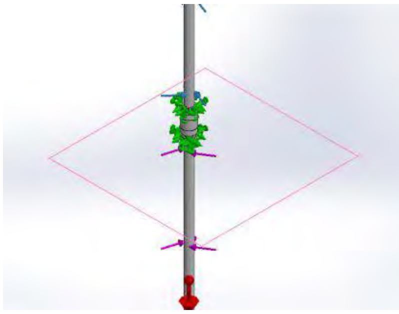
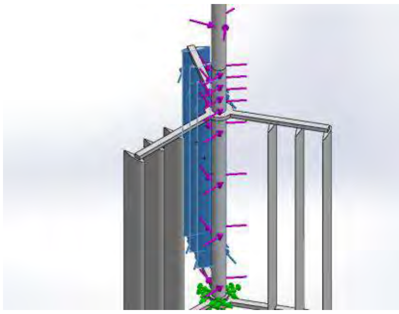
Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 12 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-258.171	-179.647	-0.0560022	314.524
Reaction Moment(N.m)	6.29032e-009	1.56781e-008	1.11655e-008	2.02494e-008

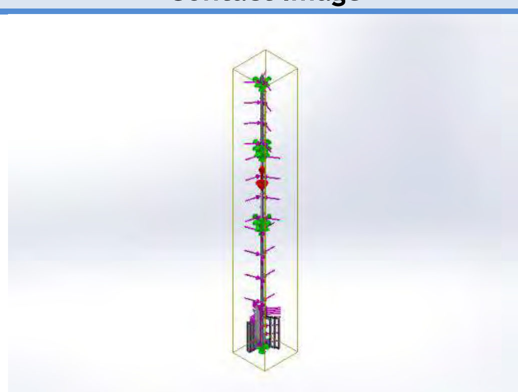
Load name	Load Image	Load Details
Torque-1		**Entities:** 3 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-2		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-3		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg

Gravity-1		**Reference:** Top Plane **Values:** 0 0 -9.81 **Units:** SI
Force-1		**Entities:** 3 face(s) **Type:** Apply normal force **Value:** 1657.5 N **Phase Angle:** 0 **Units:** deg

Connector Definitions

No Data

Contact Information

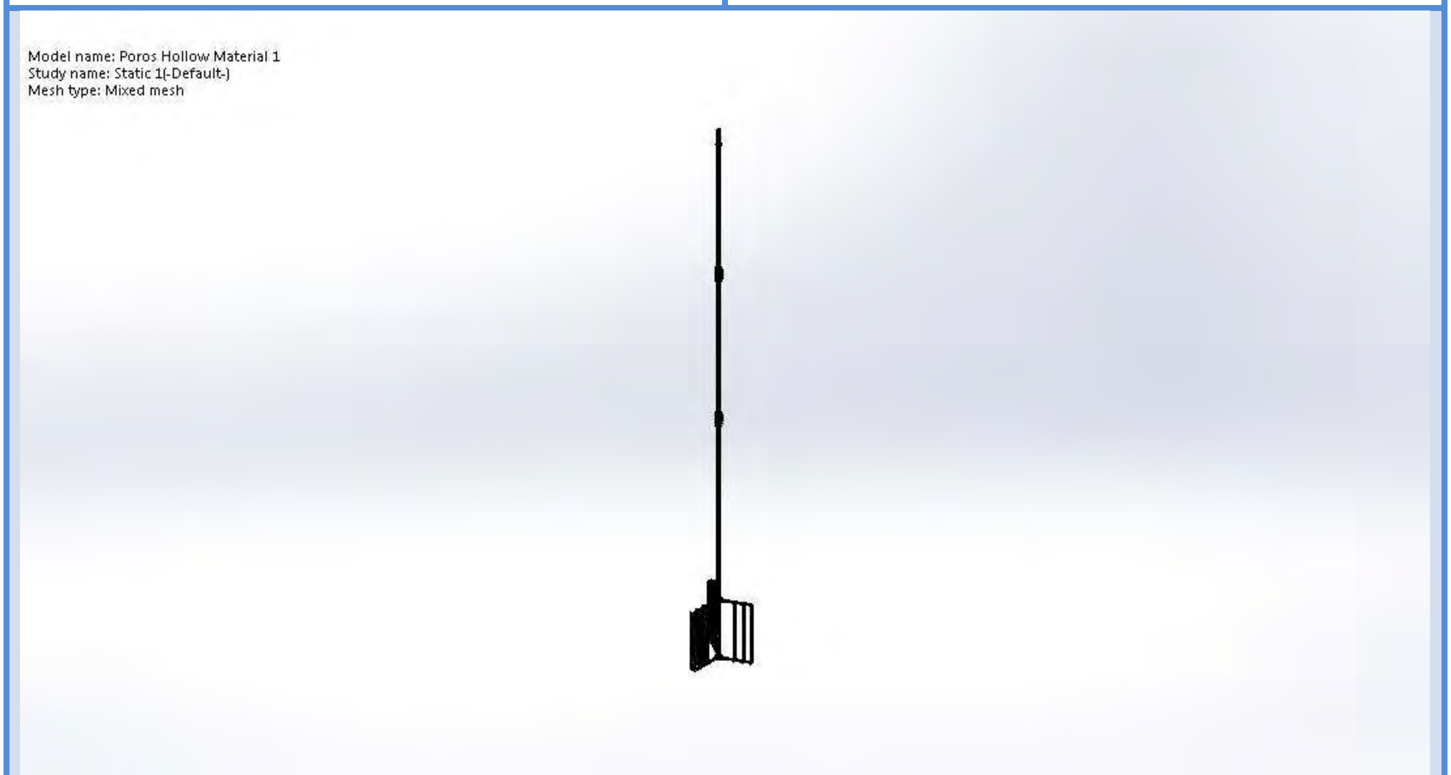
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Incompatible mesh

Mesh Information

Mesh type	Mixed Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Jacobian check for shell	On
Element Size	20.1415 mm
Tolerance	1.00707 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh Information - Details

Total Nodes	74465
Total Elements	36513
Time to complete mesh(hh;mm;ss):	00:04:04
Computer name:	TK02-PC



Sensor Details
No Data

Resultant Forces

Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	4158.9	1469.75	2367.95	5006.38

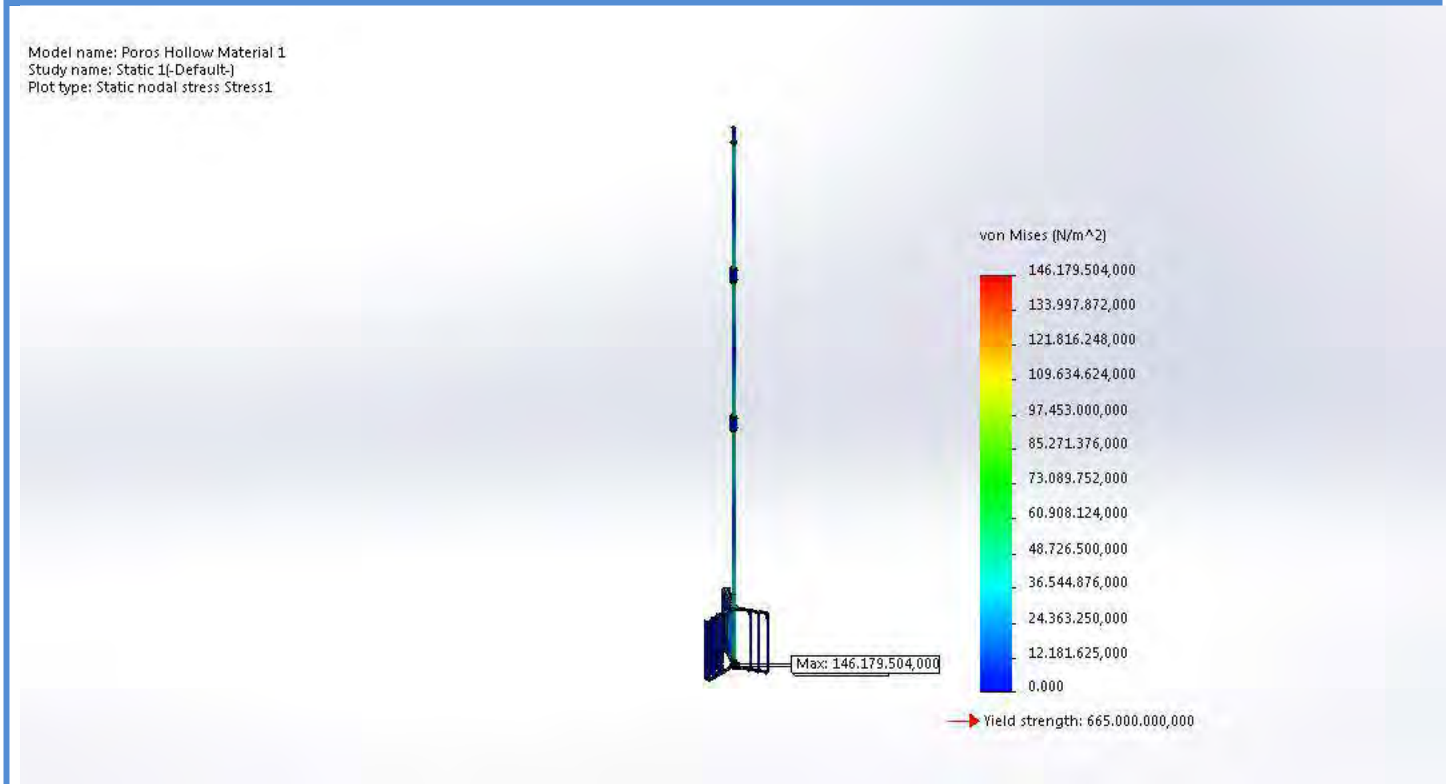
Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	-1.34651e-008	1.94018e-008	-3.96027e-009	2.39463e-008

Beams
No Data

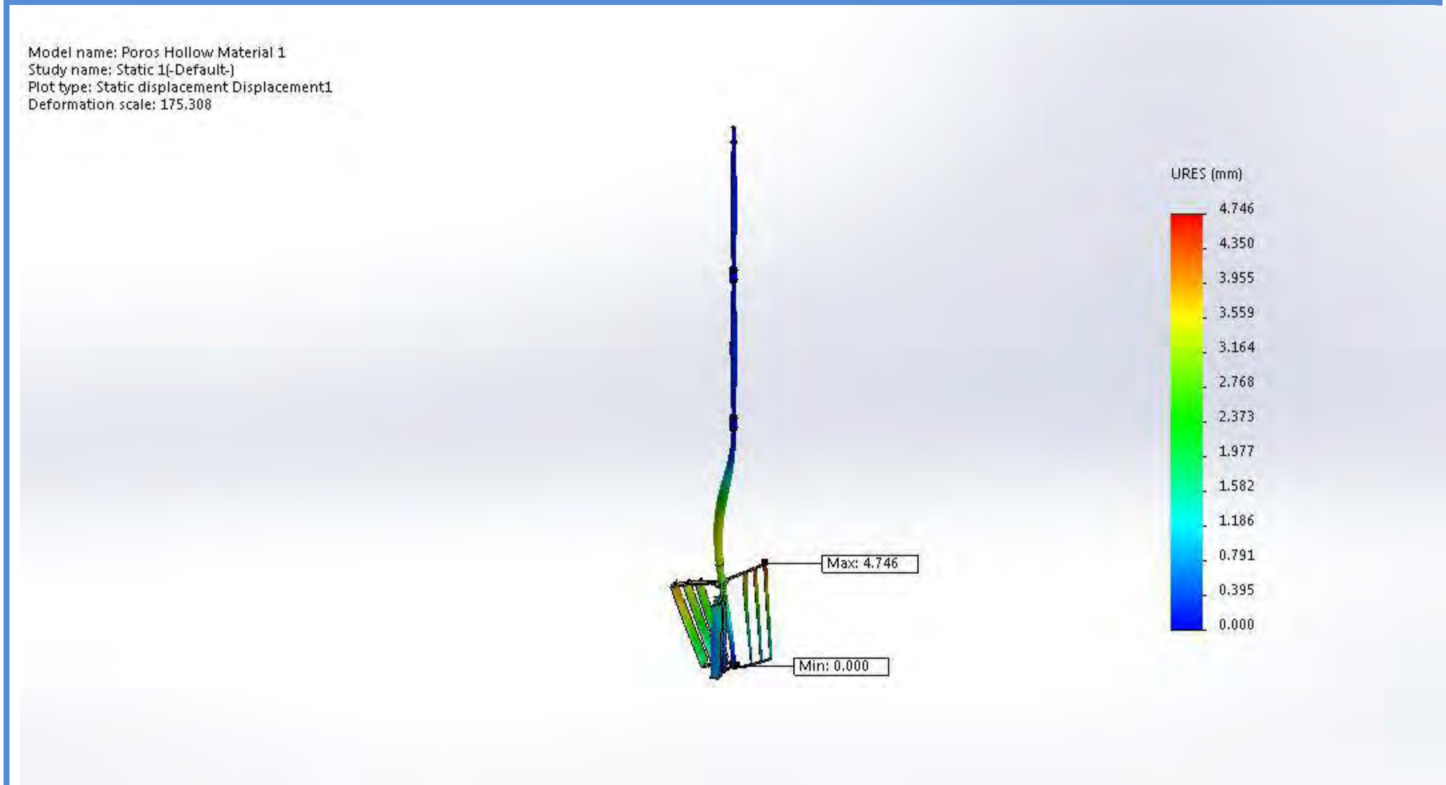
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0 N/m^2 Node: 61935	1.4618e+008 N/m^2 Node: 12693



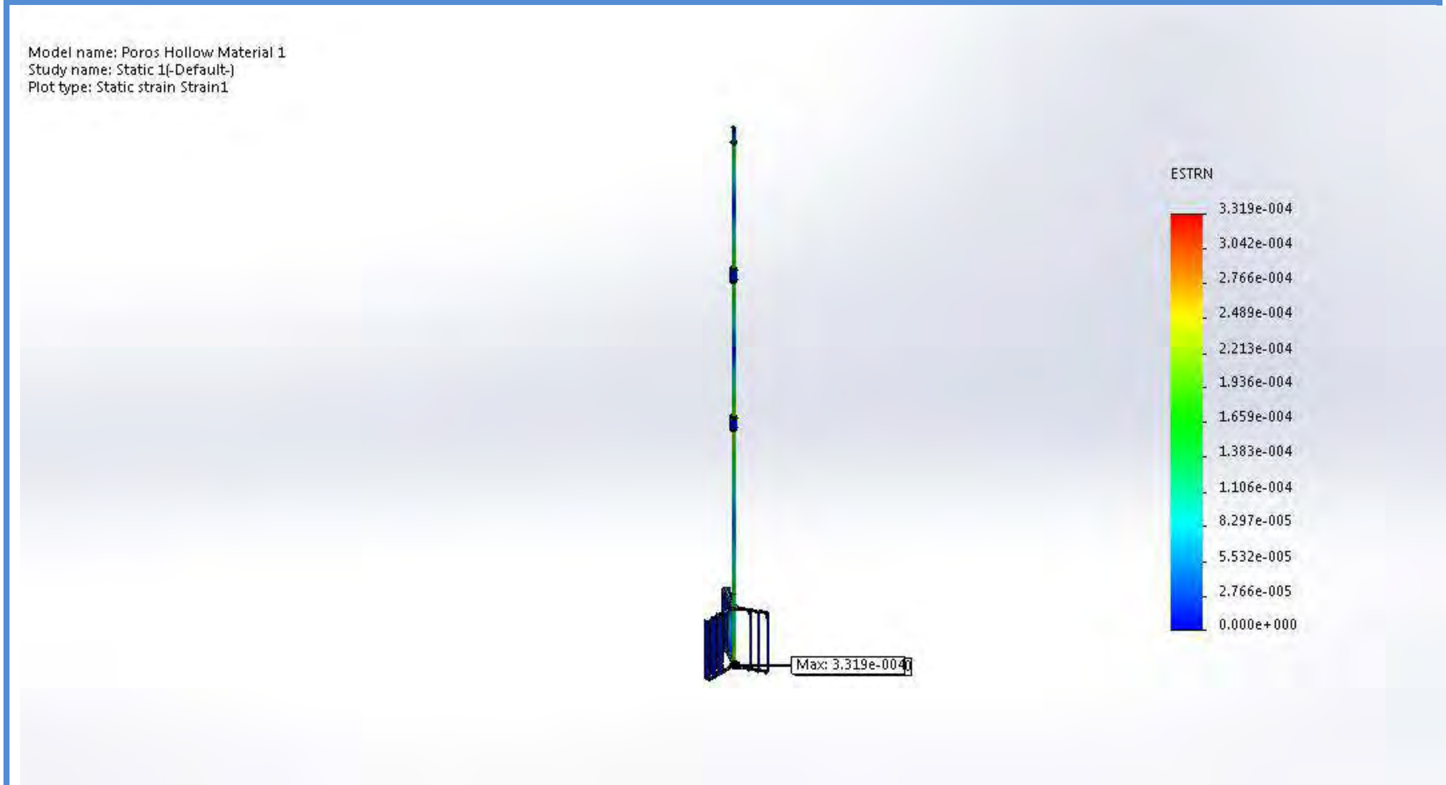
Poros Hollow Material 1-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 61935	4.74554 mm Node: 4868



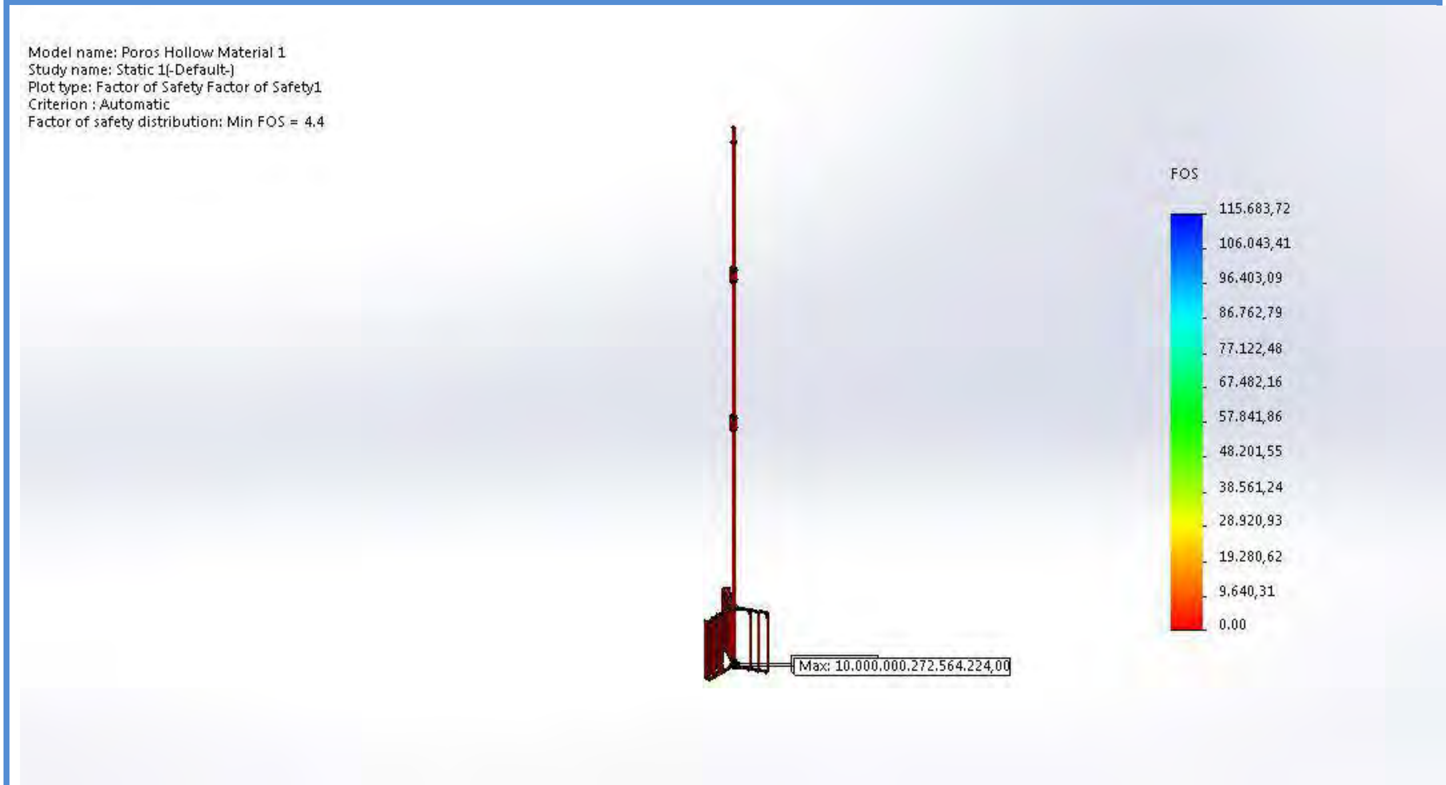
Poros Hollow Material 1-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0 Element: 30505	0.000331898 Element: 15110



Poros Hollow Material 1-Static 1-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Automatic	4.38892 Node: 12693	1e+016 Node: 61935



Poros Hollow Material 1-Static 1-Factor of Safety-Factor of Safety1

Conclusion

ATTACHMENT 7

Simulation Report of Solid Shaft Material 1

Simulation of Solid Shaft - Material 1 (High Tensile AISI 4140)

Date: 27 Juli 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

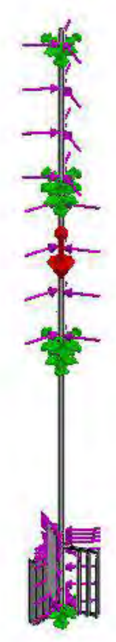
Table of Contents

Description

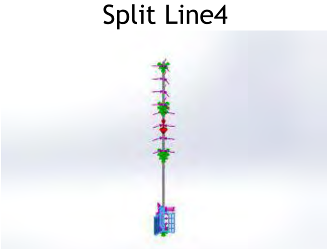
No Data

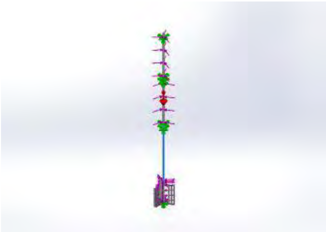
Assumptions

Model Information



Model name: Poros Pejal Material 1
Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Split Line4 	Solid Body	**Mass:92.5843 kg Volume:0.0117894 m^3 Density:7853.17 kg/m^3 Weight:907.326 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\NACA 0018.sldprt** Jun 21 15:07:01 2016

Boss-Extrude1 	Solid Body	**Mass:35.6937 kg Volume:0.00454696 m^3 Density:7850 kg/m^3 Weight:349.798 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\poros 1.SLDPRT** Jun 29 16:17:56 2016
Boss-Extrude1 	Solid Body	**Mass:30.8269 kg Volume:0.00392699 m^3 Density:7850 kg/m^3 Weight:302.103 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\poros 2.SLDPRT** Jun 29 16:17:56 2016
Body-Move/Copy1	Solid Body	**Mass:30.8269 kg Volume:0.00392699 m^3 Density:7850 kg/m^3 Weight:302.103 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\poros 3.SLDPRT** Jun 29 16:17:57 2016
Revolve1 	Solid Body	**Mass:3.9389 kg Volume:0.00050177 m^3 Density:7850 kg/m^3 Weight:38.6012 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016
Revolve1 	Solid Body	**Mass:3.9389 kg Volume:0.00050177 m^3 Density:7850 kg/m^3 Weight:38.6012 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016

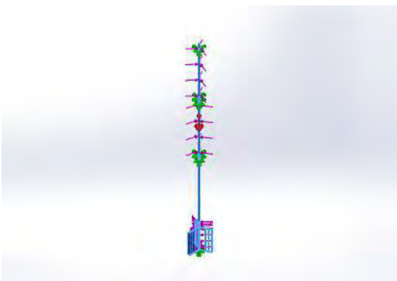
Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Mixed Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SolidWorks document (D:\Dhaifina Suci Soraya\Poros Pejal\Simulasi\Pejal)

Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

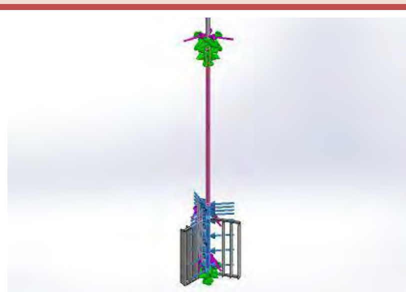
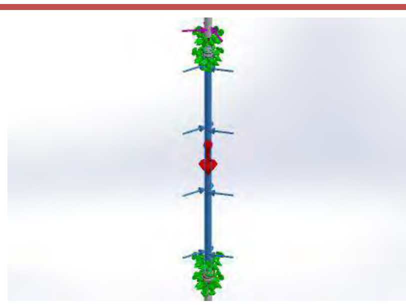
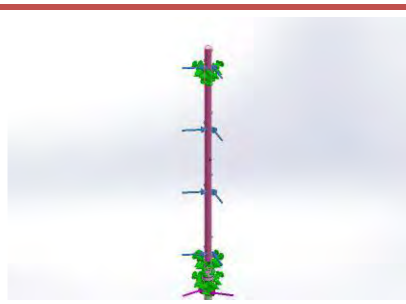
Model Reference	Properties	Components
	**Name:** AISI 4140 **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max Normal Stress **Yield strength:** 6.65e+008 N/m^2 **Tensile strength:** 8.5e+008 N/m^2 **Compressive strength:** 8.5e+008 N/m^2 **Elastic modulus:** 2.1e+011 N/m^2 **Poisson's ratio:** 0.29 **Mass density:** 7850 kg/m^3	SolidBody 1(Split Line4)(NACA 0018-1), SolidBody 1(Boss-Extrude1)(poros 1-1), SolidBody 1(Boss-Extrude1)(poros 2-1), SolidBody 1(Body-Move/Copy1)(poros 3-1), SolidBody 1(Revolve1)(soupling-1), SolidBody 1(Revolve1)(soupling-2), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-11), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-12), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-13), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-14), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-15), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-16)
Curve Data:N/A		

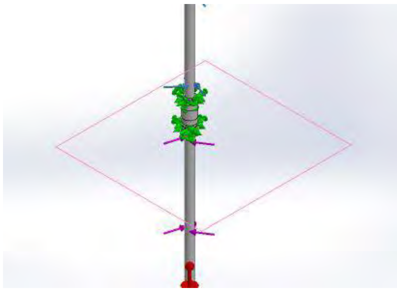
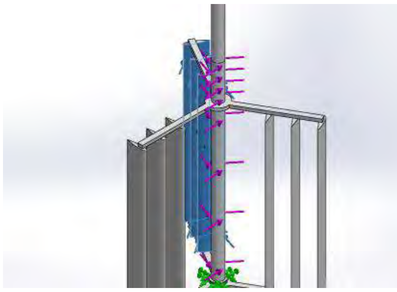
Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 12 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-309.879	-164.95	9.31443	351.17
Reaction Moment(N.m)	-5.9414e-008	1.43002e-008	-8.63247e-008	1.05766e-007

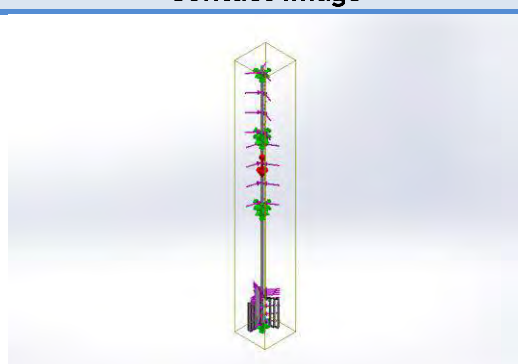
Load name	Load Image	Load Details
Torque-1		**Entities:** 2 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-2		**Entities:** 1 face(s) **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-3		**Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg

Gravity-1		**Reference:** Top Plane **Values:** 0 0 -9.81 **Units:** SI
Force-1		**Entities:** 3 face(s) **Type:** Apply normal force **Value:** 1657.5 N **Phase Angle:** 0 **Units:** deg

Connector Definitions

No Data

Contact Information

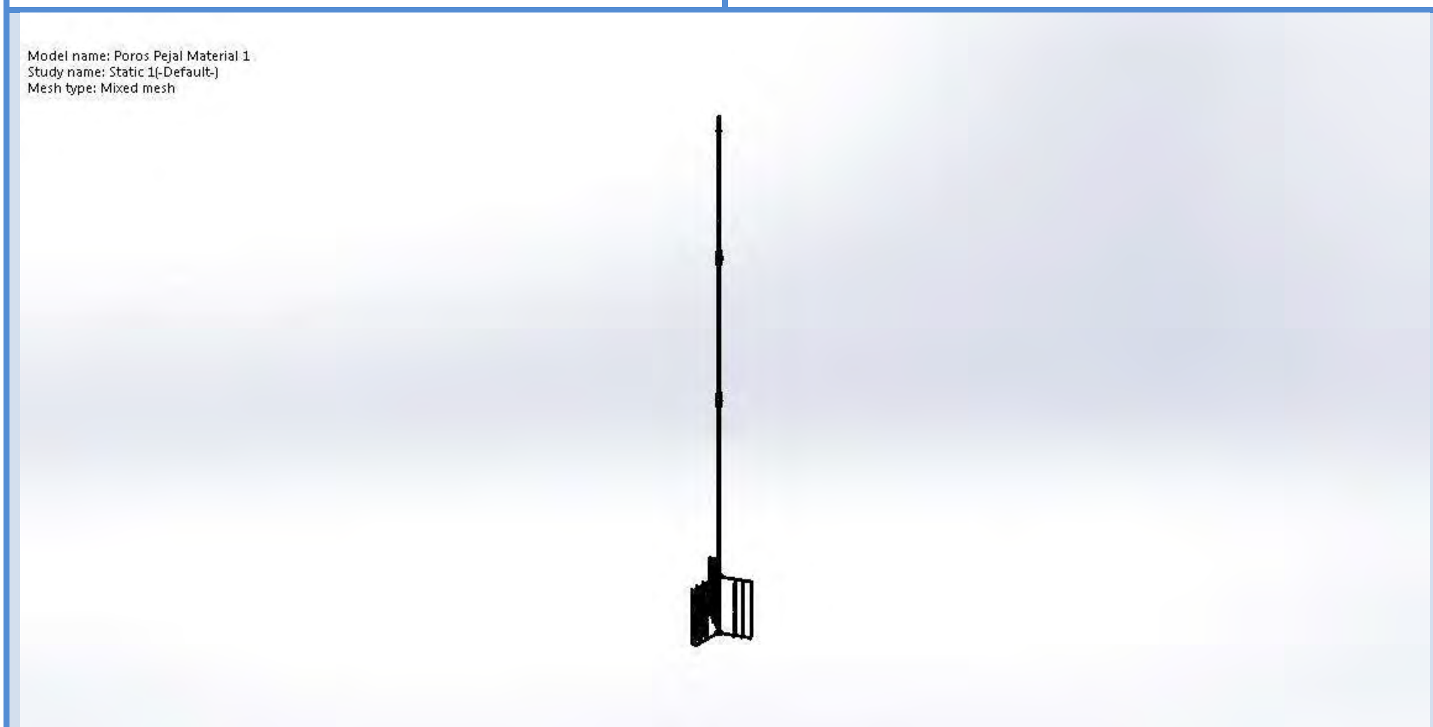
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Incompatible mesh

Mesh Information

Mesh type	Mixed Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Jacobian check for shell	On
Element Size	20.1415 mm
Tolerance	1.00707 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh Information - Details

Total Nodes	70365
Total Elements	35929
Time to complete mesh(hh;mm;ss):	00:04:12
Computer name:	TK02-PC



Sensor Details
No Data

Resultant Forces

Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	4158.87	1936.3	2367.96	5162.63

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	4.64656e-008	5.44881e-008	5.69562e-008	9.14987e-008

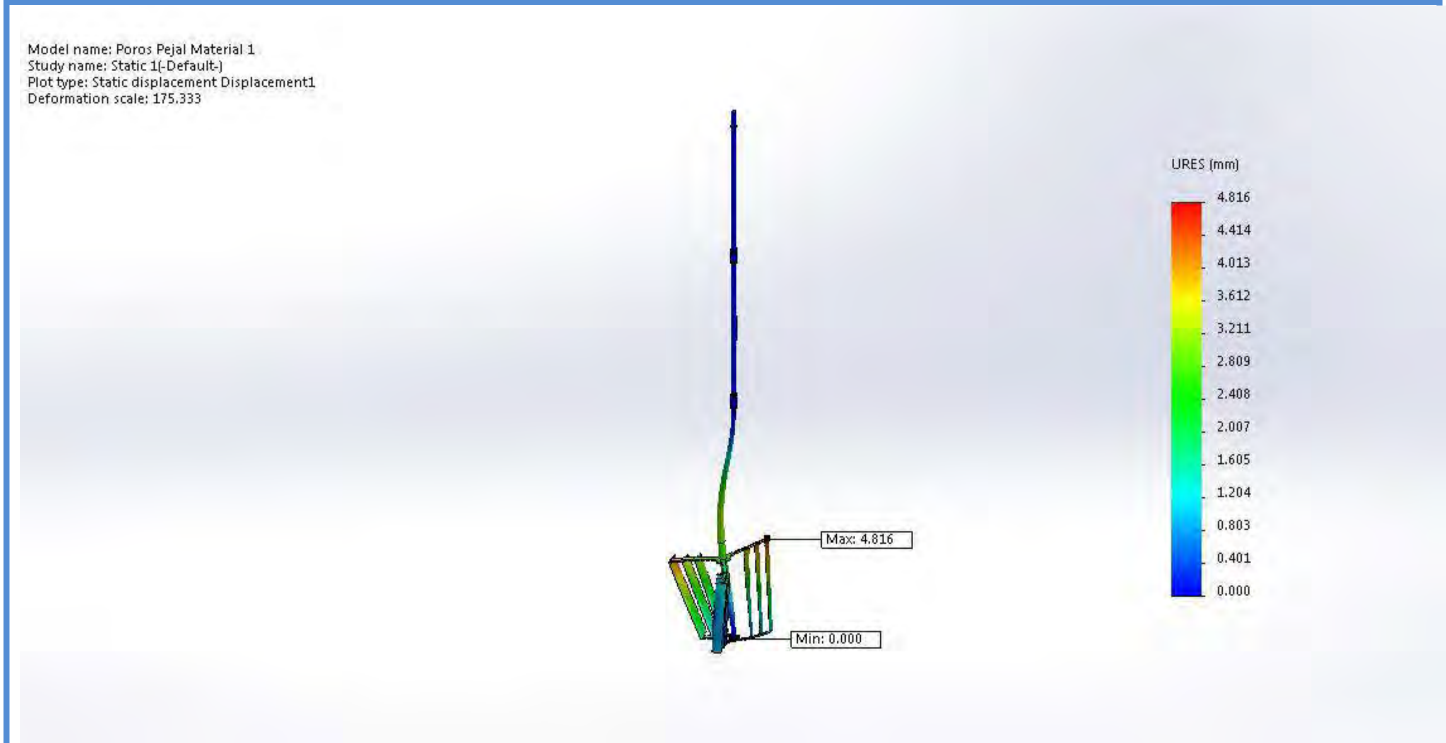
Beams
No Data

Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0 N/m^2 Node: 57835	1.44062e+008 N/m^2 Node: 12693

Poros Pejal Material 1-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 57835	4.81578 mm Node: 4868



Poros Pejal Material 1-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0 Element: 29921	0.000385895 Element: 15110

Poros Pejal Material 1-Static 1-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Max Shear Stress (Tresca)	4.53479 Node: 12693	1e+016 Node: 57835

Poros Pejal Material 1-Static 1-Factor of Safety-Factor of Safety1

Name	Type
Displacement1{1}	Deformed Shape

Poros Pejal Material 1-Static 1-Displacement-Displacement1{1}

Conclusion

ATTACHMENT 8

Simulation Report of Hollow Shaft Material 2

Simulation of Hollow Shaft - Material 2

(Medium Tensile Carbon Steel AISI 1045)

Date: 28 Juli 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

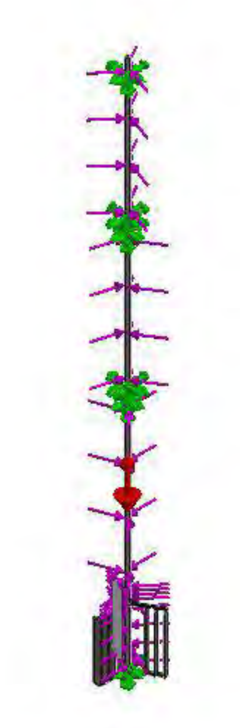
Table of Contents

Description

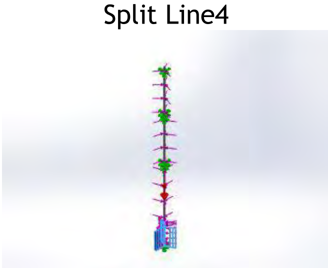
No Data

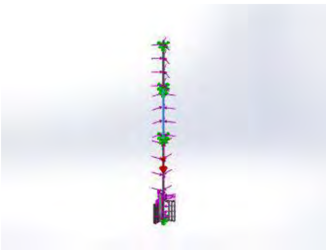
Assumptions

Model Information



Model name: Poros Hollow Material 2
Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Split Line4 	Solid Body	**Mass:92.5843 kg** **Volume:0.0117894 m^3** **Density:7853.17 kg/m^3** **Weight:907.326 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\NACA 0018.sldprt** Jul 27 23:24:05 2016

Boss-Extrude1 	Solid Body	**Mass:18.2038 kg Volume:0.00231895 m^3 Density:7850 kg/m^3 Weight:178.397 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\poros 1.SLDPRT** Jun 27 15:07:39 2016
Boss-Extrude1 	Solid Body	**Mass:15.7217 kg Volume:0.00200277 m^3 Density:7850 kg/m^3 Weight:154.073 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\poros 2.SLDPRT** Jun 21 15:07:01 2016
Body-Move/Copy1	Solid Body	**Mass:15.7217 kg Volume:0.00200277 m^3 Density:7850 kg/m^3 Weight:154.073 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\poros 3.SLDPRT** Jun 21 15:07:01 2016
Revolve1 	Solid Body	**Mass:3.9389 kg Volume:0.00050177 m^3 Density:7850 kg/m^3 Weight:38.6012 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016
Revolve1 	Solid Body	**Mass:3.9389 kg Volume:0.00050177 m^3 Density:7850 kg/m^3 Weight:38.6012 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016

Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Mixed Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SolidWorks document (D:\Dhaifina Suci Soraya\Poros Hollow\Simulasi\Material 2 AISI 1045 - Hollow)

Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

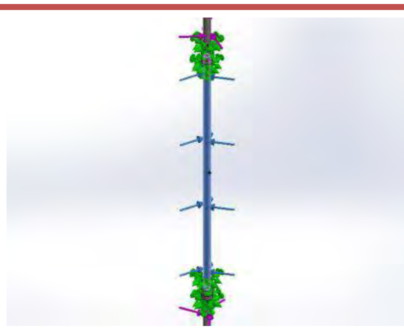
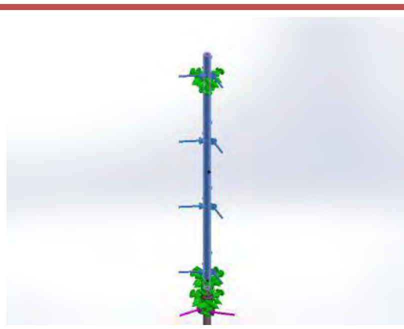
Model Reference	Properties	Components
	**Name:** AISI 1045 Steel, cold drawn **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 5.3e+008 N/m^2 **Tensile strength:** 6.25e+008 N/m^2 **Elastic modulus:** 2.05e+011 N/m^2 **Poisson's ratio:** 0.29 **Mass density:** 7850 kg/m^3 **Shear modulus:** 8e+010 N/m^2 **Thermal expansion coefficient:** 1.15e-005 /Kelvin	SolidBody 1(Split Line4)(NACA 0018-1), SolidBody 1(Boss-Extrude1)(poros 1-1), SolidBody 1(Boss-Extrude1)(poros 2-1), SolidBody 1(Body-Move/Copy1)(poros 3-1), SolidBody 1(Revolve1)(soupling-1), SolidBody 1(Revolve1)(soupling-2), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-11), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-12), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-13), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-14), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-15), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-16)
Curve Data:N/A		

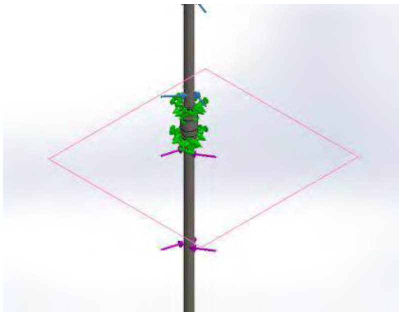
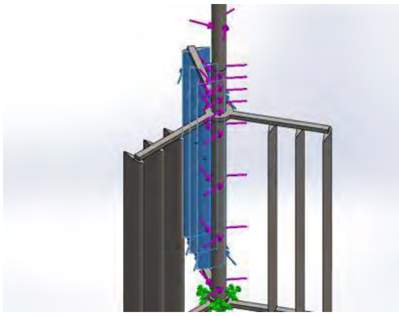
Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 12 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-258.171	-179.647	-0.0559792	314.524
Reaction Moment(N.m)	-7.0636e-008	-5.38823e-009	-4.68319e-009	7.09958e-008

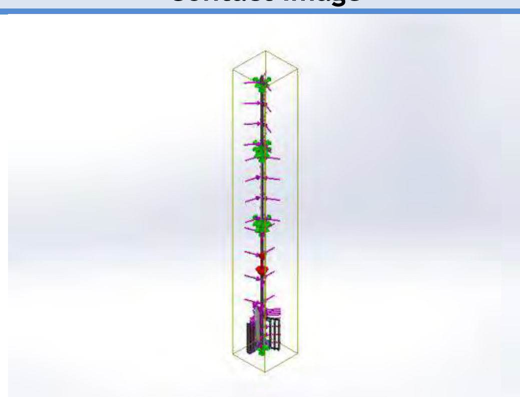
Load name	Load Image	Load Details
Torque-1		**Entities:** 3 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-2		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-3		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg

Gravity-1		**Reference:** Top Plane **Values:** 0 0 -9.81 **Units:** SI
Force-1		**Entities:** 3 face(s) **Type:** Apply normal force **Value:** 1657.5 N **Phase Angle:** 0 **Units:** deg

Connector Definitions

No Data

Contact Information

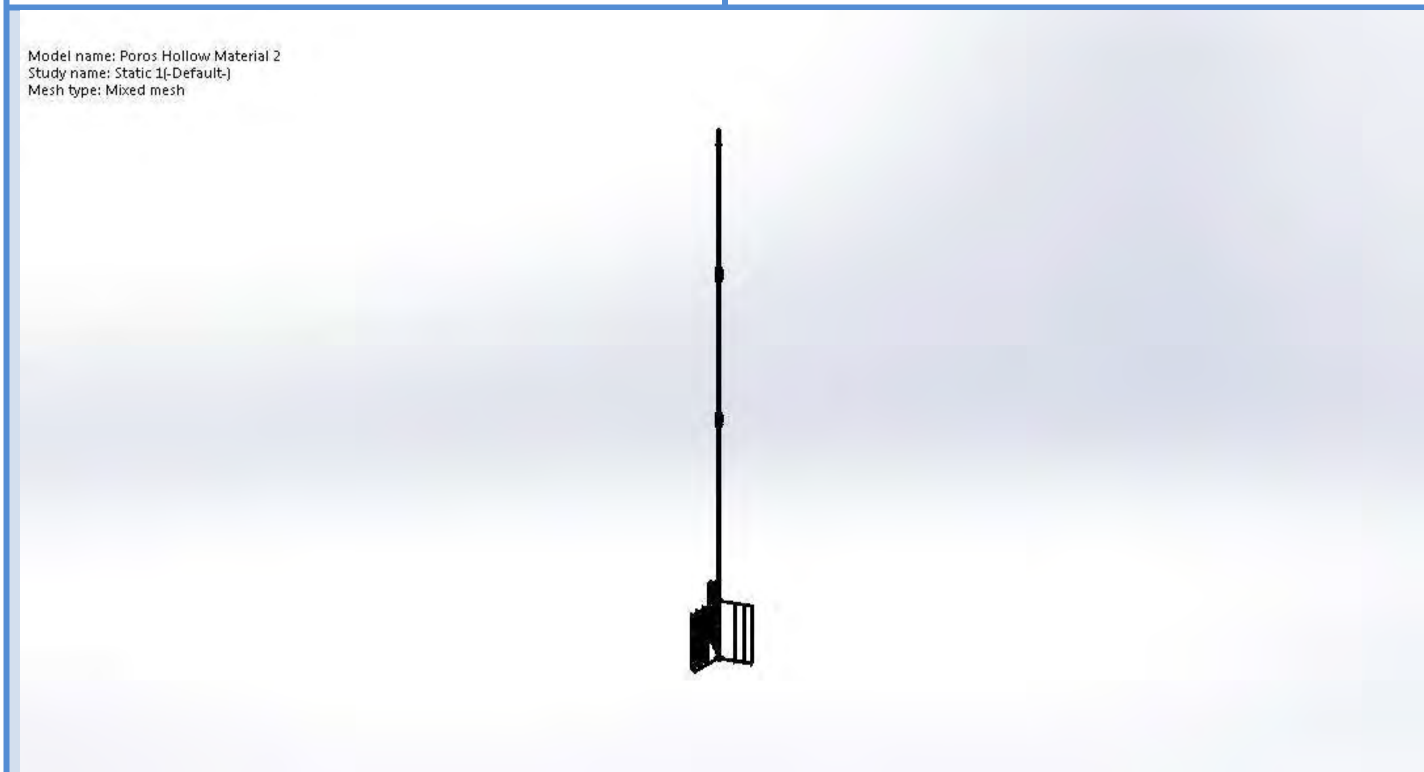
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Incompatible mesh

Mesh Information

Mesh type	Mixed Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Jacobian check for shell	On
Maximum element size	0 mm
Minimum element size	0 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh Information - Details

Total Nodes	74465
Total Elements	36513
Time to complete mesh(hh;mm;ss):	00:03:06
Computer name:	TK02-PC



Sensor Details

No Data

Resultant Forces

Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	4158.9	1469.76	2367.96	5006.38

Reaction Moments

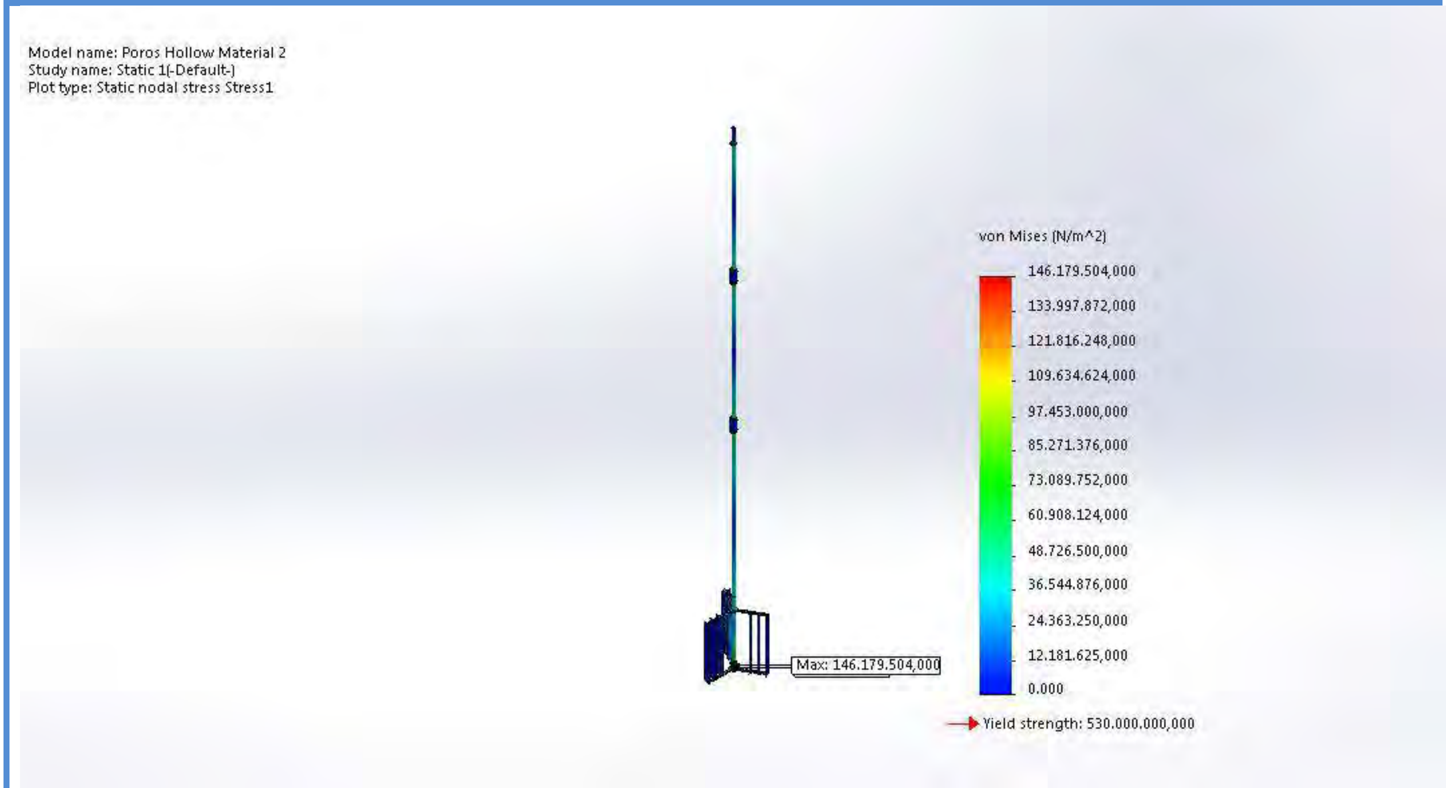
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	-2.08654e-008	-6.22119e-009	-1.64587e-010	2.17737e-008

Beams

No Data

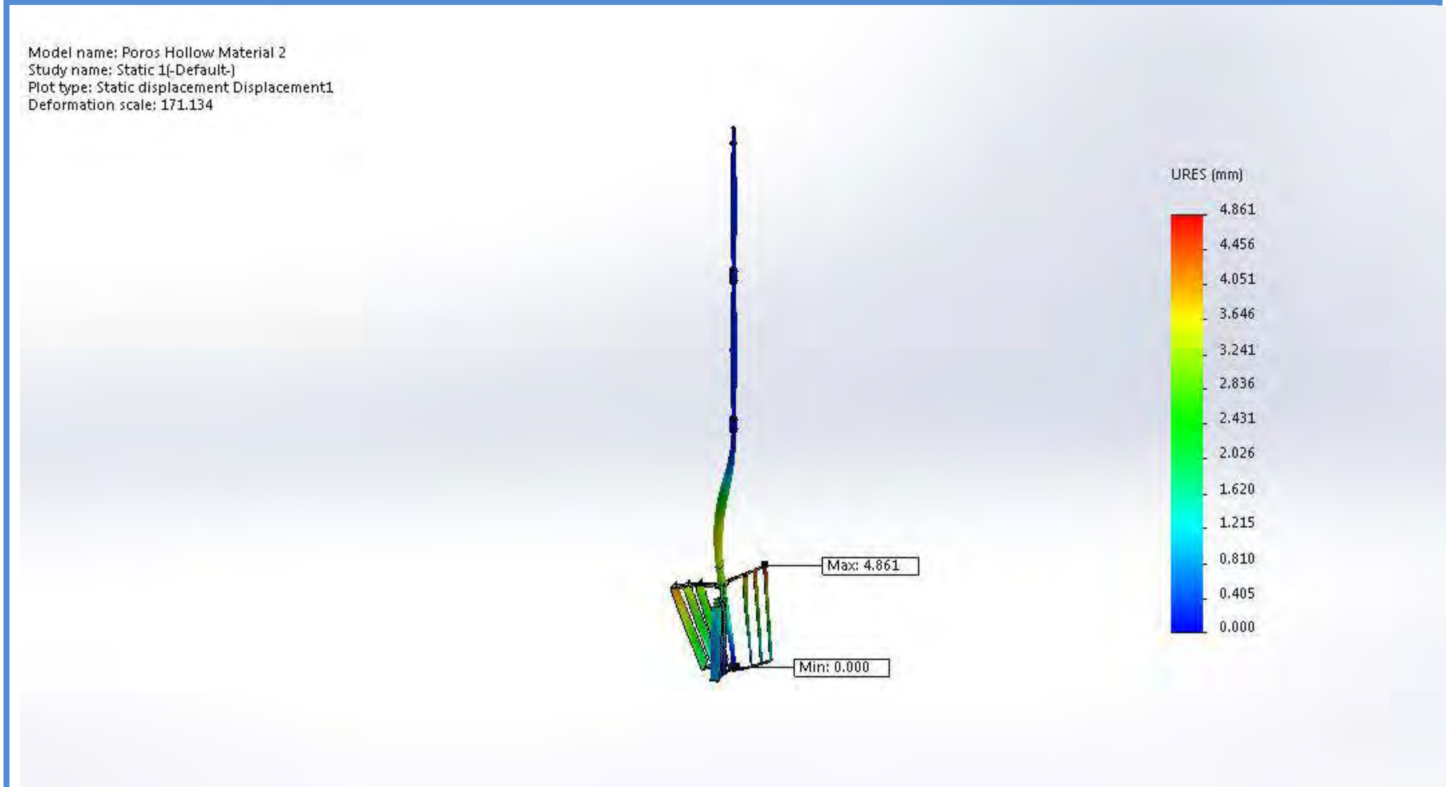
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0 N/m^2 Node: 61935	1.4618e+008 N/m^2 Node: 12693



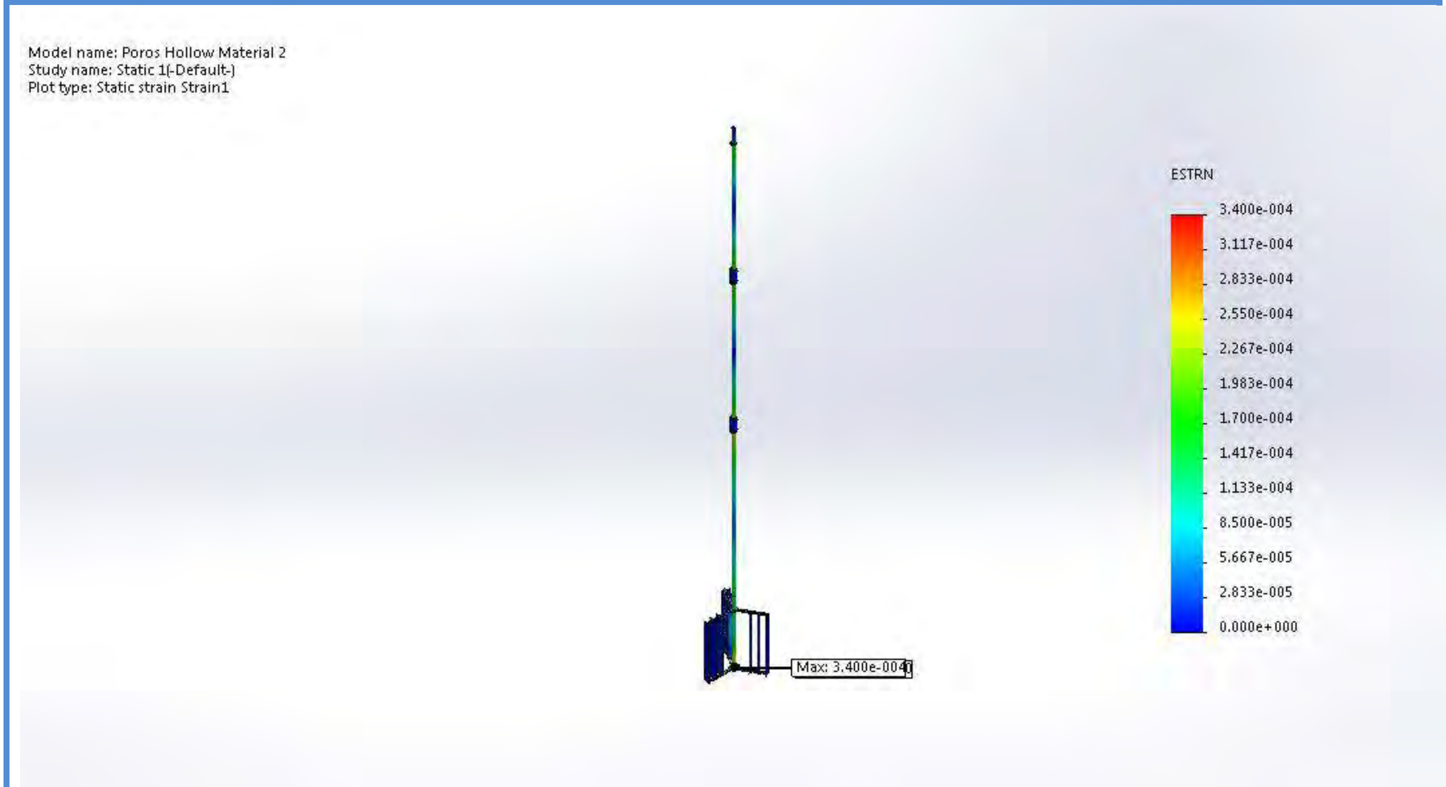
Poros Hollow Material 2-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 61935	4.86128 mm Node: 4868



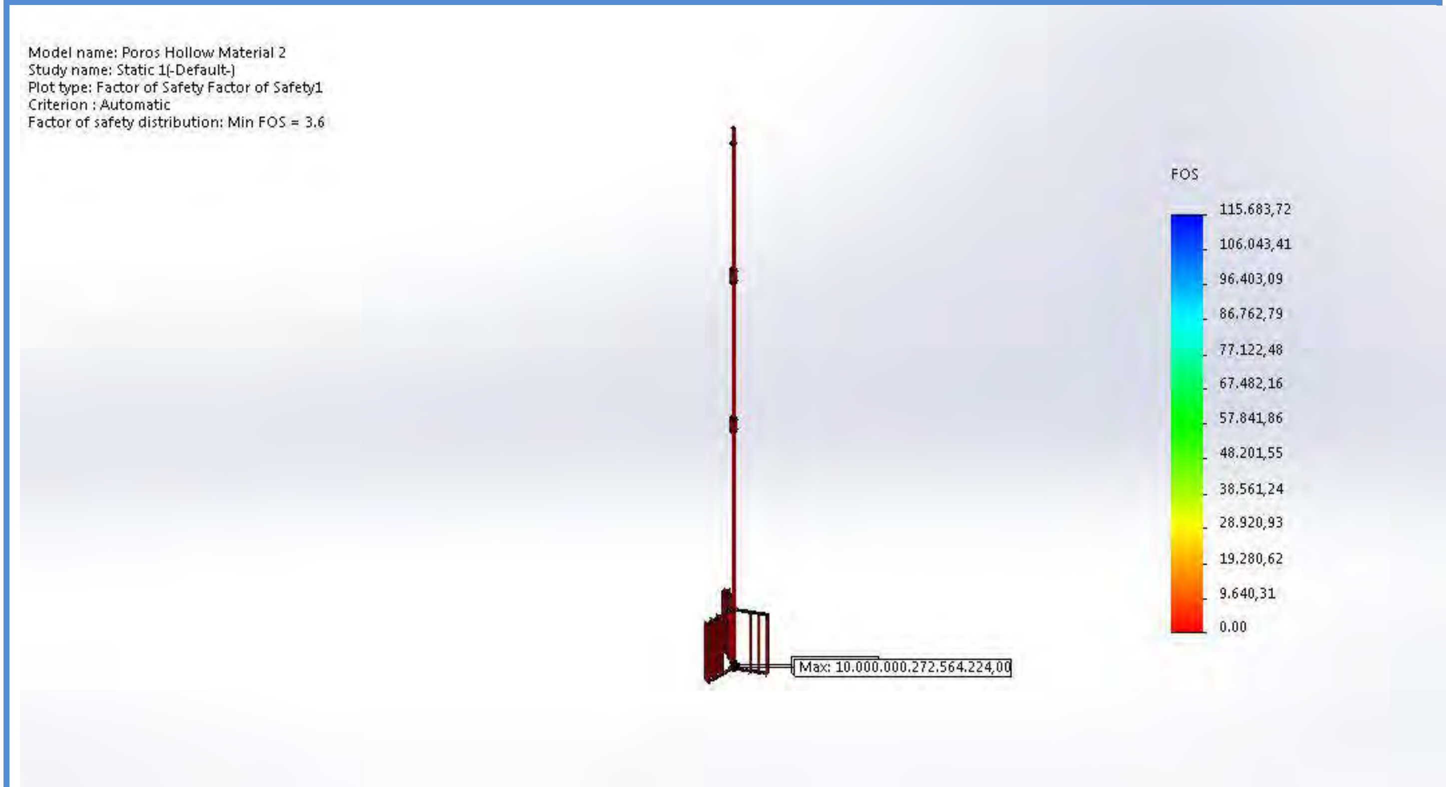
Poros Hollow Material 2-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0 Element: 30505	0.000339993 Element: 15110



Poros Hollow Material 2-Static 1-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Automatic	3.62568 Node: 12693	1e+016 Node: 61935



Poros Hollow Material 2-Static 1-Factor of Safety-Factor of Safety1

Conclusion

ATTACHMENT 9

Simulation Report of Solid Shaft Material 2

Simulation of Solid Shaft - Material 2 (Medium Tensile Carbon Steel AISI 1045)

Date: 28 Juli 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

Table of Contents

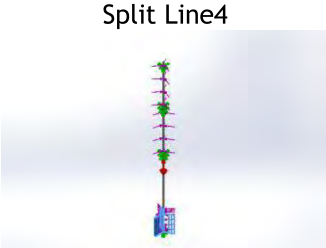
Description

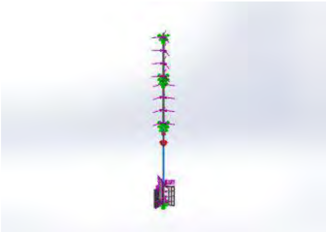
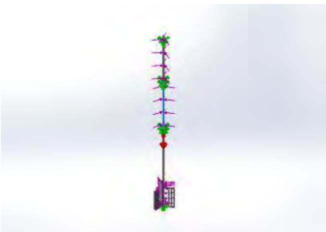
No Data

Assumptions

Model Information

Model name: Poros Pejal Material 2
Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Split Line4 	Solid Body	**Mass:92.5843 kg** **Volume:0.0117894 m^3** **Density:7853.17 kg/m^3** **Weight:907.326 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\NACA 0018.sldprt** Jul 27 23:24:05 2016

Boss-Extrude1 	Solid Body	**Mass:35.6937 kg Volume:0.00454696 m^3 Density:7850 kg/m^3 Weight:349.798 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\poros 1.SLDPRT** Jun 29 16:17:56 2016
Boss-Extrude1 	Solid Body	**Mass:30.8269 kg Volume:0.00392699 m^3 Density:7850 kg/m^3 Weight:302.103 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\poros 2.SLDPRT** Jun 29 16:17:56 2016
Body-Move/Copy1	Solid Body	**Mass:30.8269 kg Volume:0.00392699 m^3 Density:7850 kg/m^3 Weight:302.103 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\poros 3.SLDPRT** Jun 29 16:17:57 2016
Revolve1 	Solid Body	**Mass:3.9389 kg Volume:0.00050177 m^3 Density:7850 kg/m^3 Weight:38.6012 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016
Revolve1 	Solid Body	**Mass:3.9389 kg Volume:0.00050177 m^3 Density:7850 kg/m^3 Weight:38.6012 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016

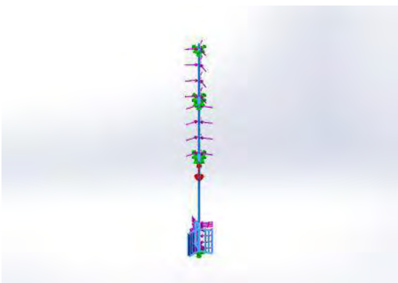
Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Mixed Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SolidWorks document (D:\Dhaifina Suci Soraya\Poros Pejal\Simulasi\Material 2 AISI 1045 - Solid)

Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

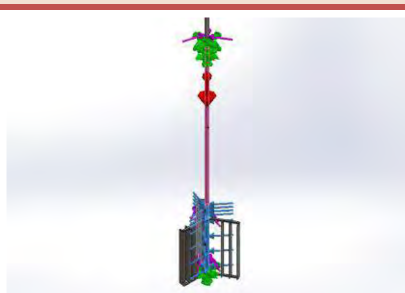
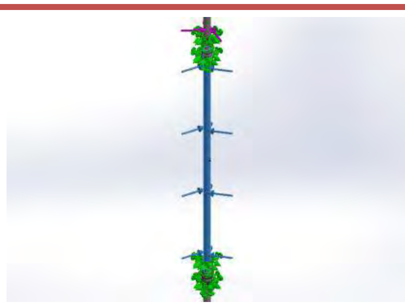
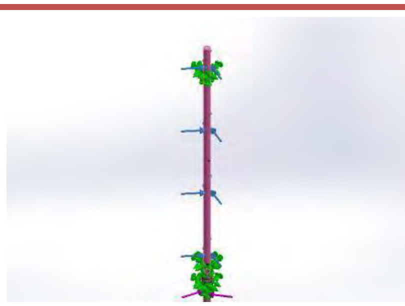
Model Reference	Properties	Components
	**Name:** AISI 1045 Steel, cold drawn **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 5.3e+008 N/m^2 **Tensile strength:** 6.25e+008 N/m^2 **Elastic modulus:** 2.05e+011 N/m^2 **Poisson's ratio:** 0.29 **Mass density:** 7850 kg/m^3 **Shear modulus:** 8e+010 N/m^2 **Thermal expansion coefficient:** 1.15e-005 /Kelvin	SolidBody 1(Split Line4)(NACA 0018-1), SolidBody 1(Boss-Extrude1)(poros 1-1), SolidBody 1(Boss-Extrude1)(poros 2-1), SolidBody 1(Body-Move/Copy1)(poros 3-1), SolidBody 1(Revolve1)(soupling-1), SolidBody 1(Revolve1)(soupling-2), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-11), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-12), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-13), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-14), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-15), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-16)
Curve Data:N/A		

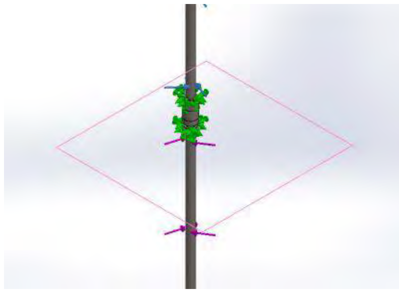
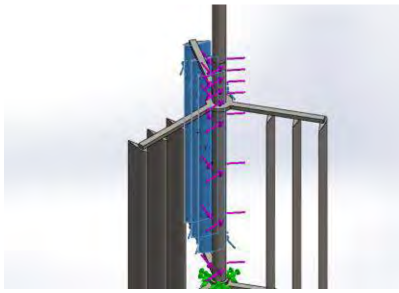
Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 12 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-309.879	-164.951	9.31437	351.17
Reaction Moment(N.m)	-8.57355e-008	-5.25832e-008	-2.01106e-008	1.02567e-007

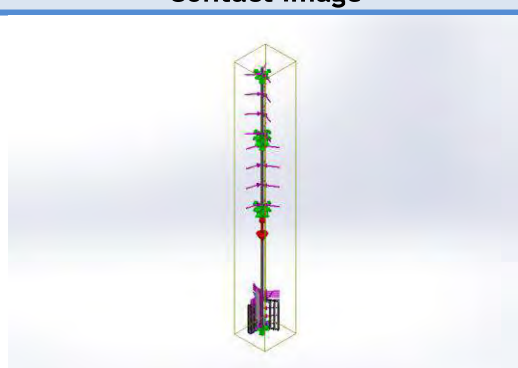
Load name	Load Image	Load Details
Torque-1		**Entities:** 2 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-2		**Entities:** 1 face(s) **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-3		**Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg

Gravity-1		**Reference:** Top Plane **Values:** 0 0 -9.81 **Units:** SI
Force-1		**Entities:** 3 face(s) **Type:** Apply normal force **Value:** 1657.5 N **Phase Angle:** 0 **Units:** deg

Connector Definitions

No Data

Contact Information

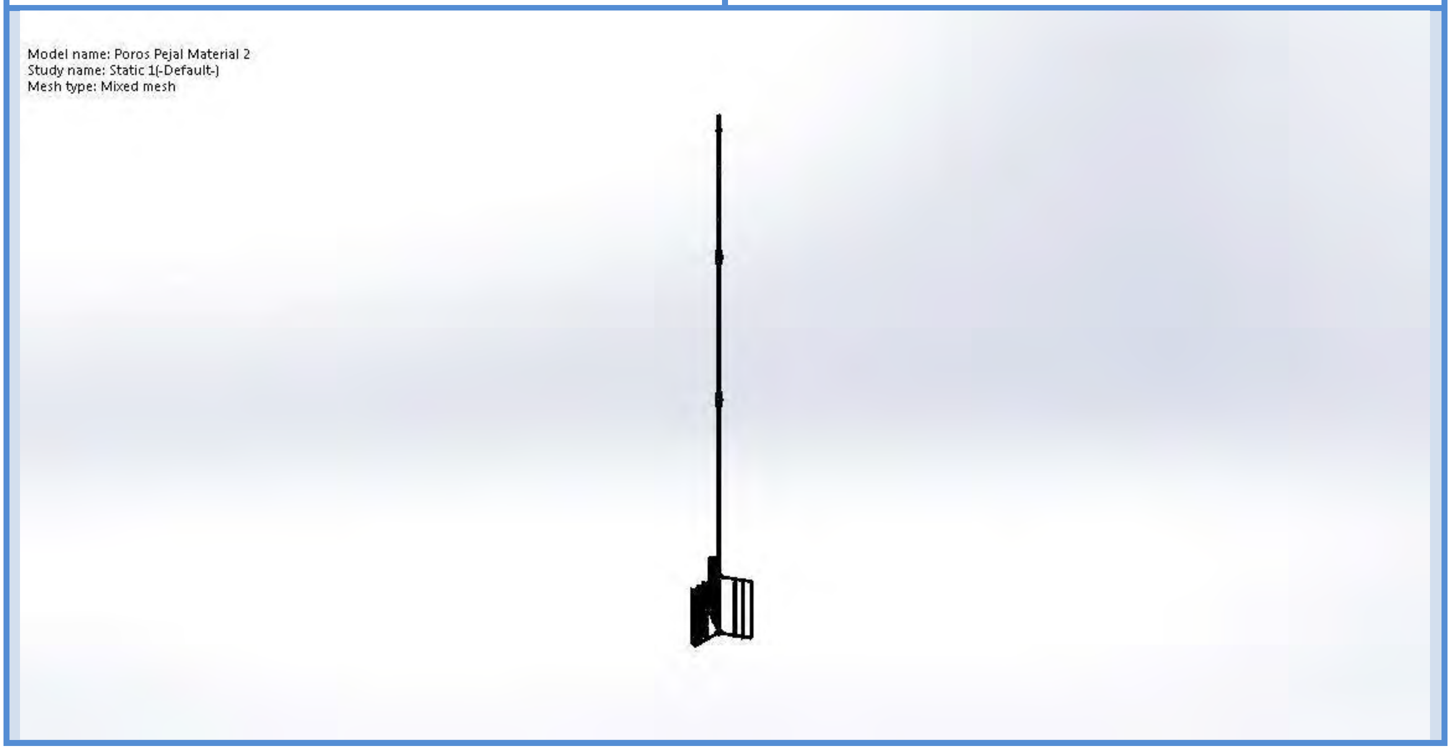
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Incompatible mesh

Mesh Information

Mesh type	Mixed Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Jacobian check for shell	On
Element Size	20.1415 mm
Tolerance	1.00707 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh Information - Details

Total Nodes	70365
Total Elements	35929
Time to complete mesh(hh;mm;ss):	00:03:30
Computer name:	TK02-PC



Sensor Details

No Data

Resultant Forces

Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	4158.87	1936.3	2367.97	5162.63

Reaction Moments

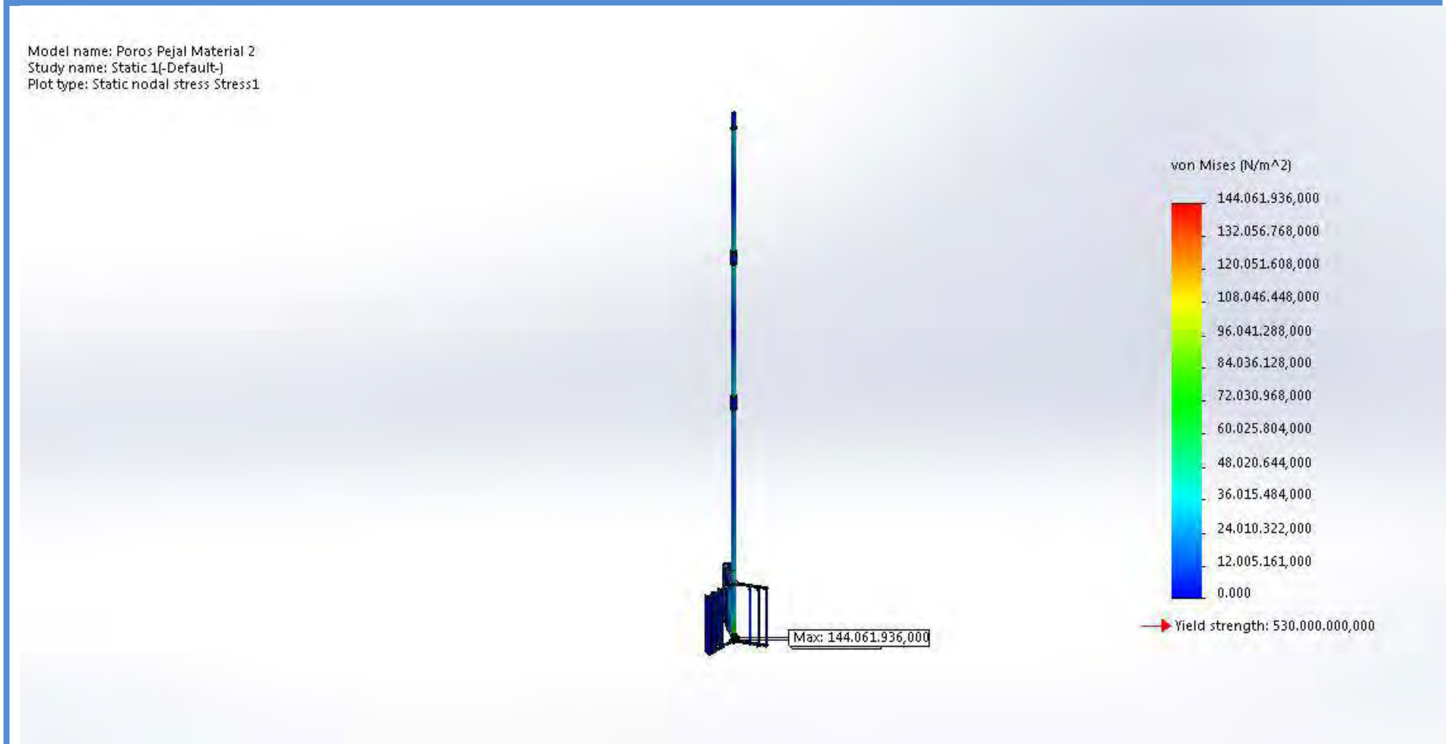
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	1.87144e-008	-1.07423e-007	1.62263e-009	1.09053e-007

Beams

No Data

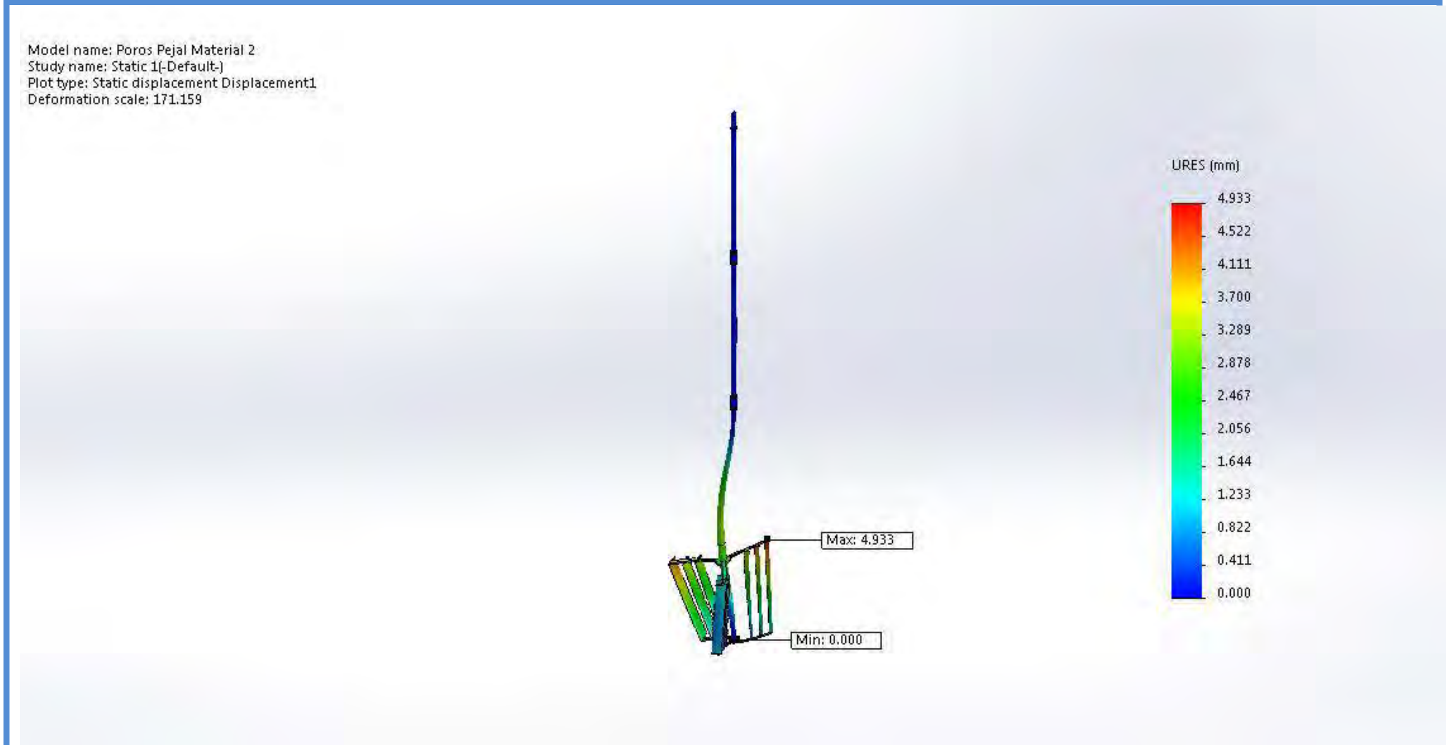
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0 N/m^2 Node: 57835	1.44062e+008 N/m^2 Node: 12693



Poros Pejal Material 2-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 57835	4.93323 mm Node: 4868



Poros Pejal Material 2-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0 Element: 29921	0.000395307 Element: 15110

Poros Pejal Material 2-Static 1-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Max von Mises Stress	3.67897 Node: 12693	1e+016 Node: 57835

Poros Pejal Material 2-Static 1-Factor of Safety-Factor of Safety1

Name	Type
Displacement1{1}	Deformed Shape

Poros Pejal Material 2-Static 1-Displacement-Displacement1{1}

Conclusion

ATTACHMENT 10

Simulation Report of Hollow Shaft Material 3

Simulation of Hollow Shaft - Material 3 (Stainless Steel AISI 316)

Date: 28 Juli 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

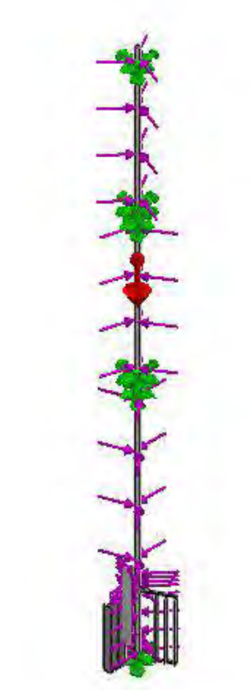
Table of Contents

Description

No Data

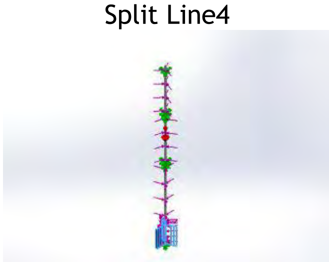
Assumptions

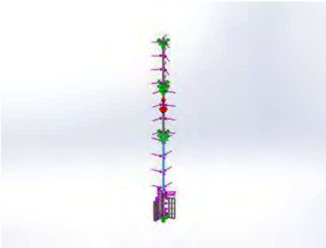
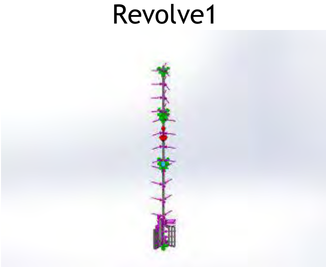
Model Information



Model name: Poros Hollow Material 3
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Split Line4 	Solid Body	**Mass:94.3534 kg** **Volume:0.0117894 m^3** **Density:8003.23 kg/m^3** **Weight:924.663 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\NACA 0018.sldprt** Jul 27 23:24:05 2016

Boss-Extrude1 	Solid Body	**Mass:18.5516 kg Volume:0.00231895 m^3 Density:8000 kg/m^3 Weight:181.806 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\poros 1.SLDPRT** Jun 27 15:07:39 2016
Boss-Extrude1 	Solid Body	**Mass:16.0221 kg Volume:0.00200277 m^3 Density:8000 kg/m^3 Weight:157.017 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\poros 2.SLDPRT** Jun 21 15:07:01 2016
Body-Move/Copy1	Solid Body	**Mass:16.0221 kg Volume:0.00200277 m^3 Density:8000 kg/m^3 Weight:157.017 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\poros 3.SLDPRT** Jun 21 15:07:01 2016
Revolve1 	Solid Body	**Mass:4.01416 kg Volume:0.00050177 m^3 Density:8000 kg/m^3 Weight:39.3388 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016
Revolve1 	Solid Body	**Mass:4.01416 kg Volume:0.00050177 m^3 Density:8000 kg/m^3 Weight:39.3388 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016

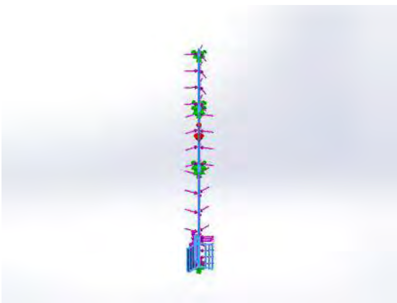
Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Mixed Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SolidWorks document (D:\Dhaifina Suci Soraya\Poros Hollow\Simulasi\Material 3 ASTM A276-98b 316-Hollow)

Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

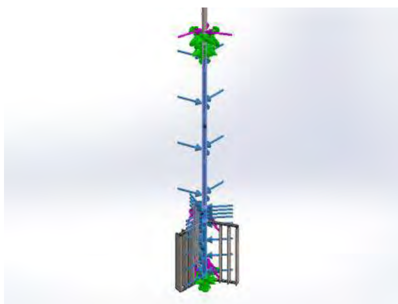
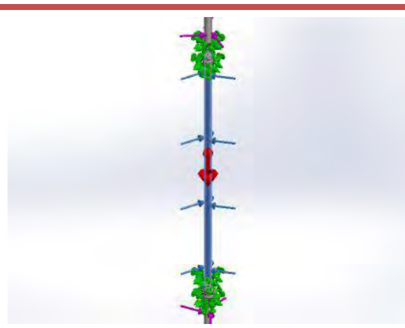
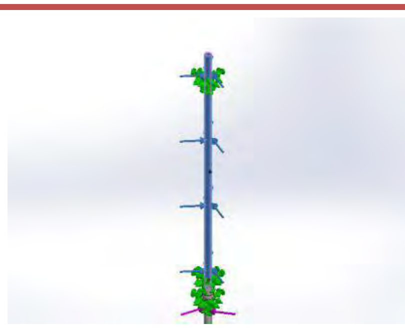
Model Reference	Properties	Components
	**Name:** AISI 316 Stainless Steel Sheet (SS) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 1.72369e+008 N/m^2 **Tensile strength:** 5.8e+008 N/m^2 **Elastic modulus:** 1.93e+011 N/m^2 **Poisson's ratio:** 0.27 **Mass density:** 8000 kg/m^3 **Thermal expansion coefficient:** 1.6e-005 /Kelvin	SolidBody 1(Split Line4)(NACA 0018-1), SolidBody 1(Boss-Extrude1)(poros 1-1), SolidBody 1(Boss-Extrude1)(poros 2-1), SolidBody 1(Body-Move/Copy1)(poros 3-1), SolidBody 1(Revolve1)(soupling-1), SolidBody 1(Revolve1)(soupling-2), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-11), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-12), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-13), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-14), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-15), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-16)
Curve Data:N/A		

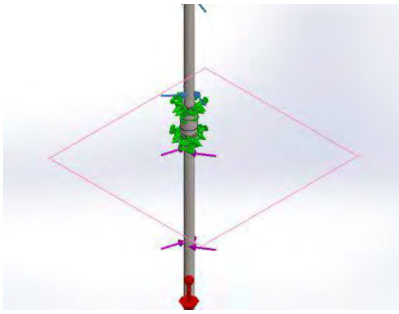
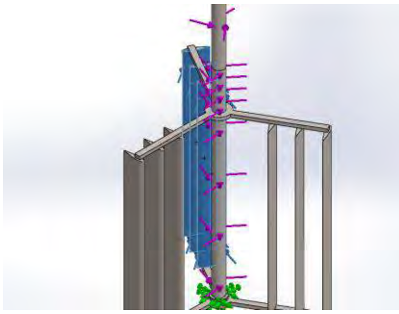
Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 12 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-256.09	-178.084	1.10247	311.925
Reaction Moment(N.m)	3.25402e-009	-1.01342e-008	-3.01264e-008	3.19514e-008

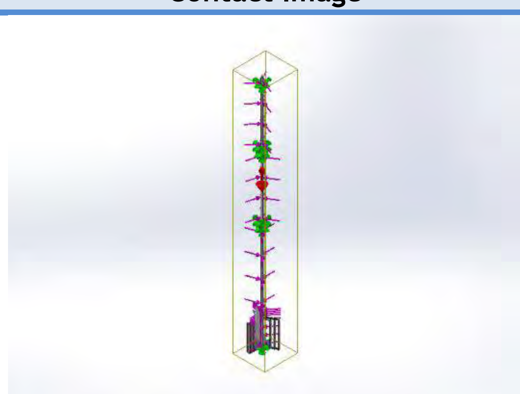
Load name	Load Image	Load Details
Torque-1		**Entities:** 3 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-2		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-3		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg

Gravity-1		**Reference:** Top Plane **Values:** 0 0 -9.81 **Units:** SI
Force-1		**Entities:** 3 face(s) **Type:** Apply normal force **Value:** 1657.5 N **Phase Angle:** 0 **Units:** deg

Connector Definitions

No Data

Contact Information

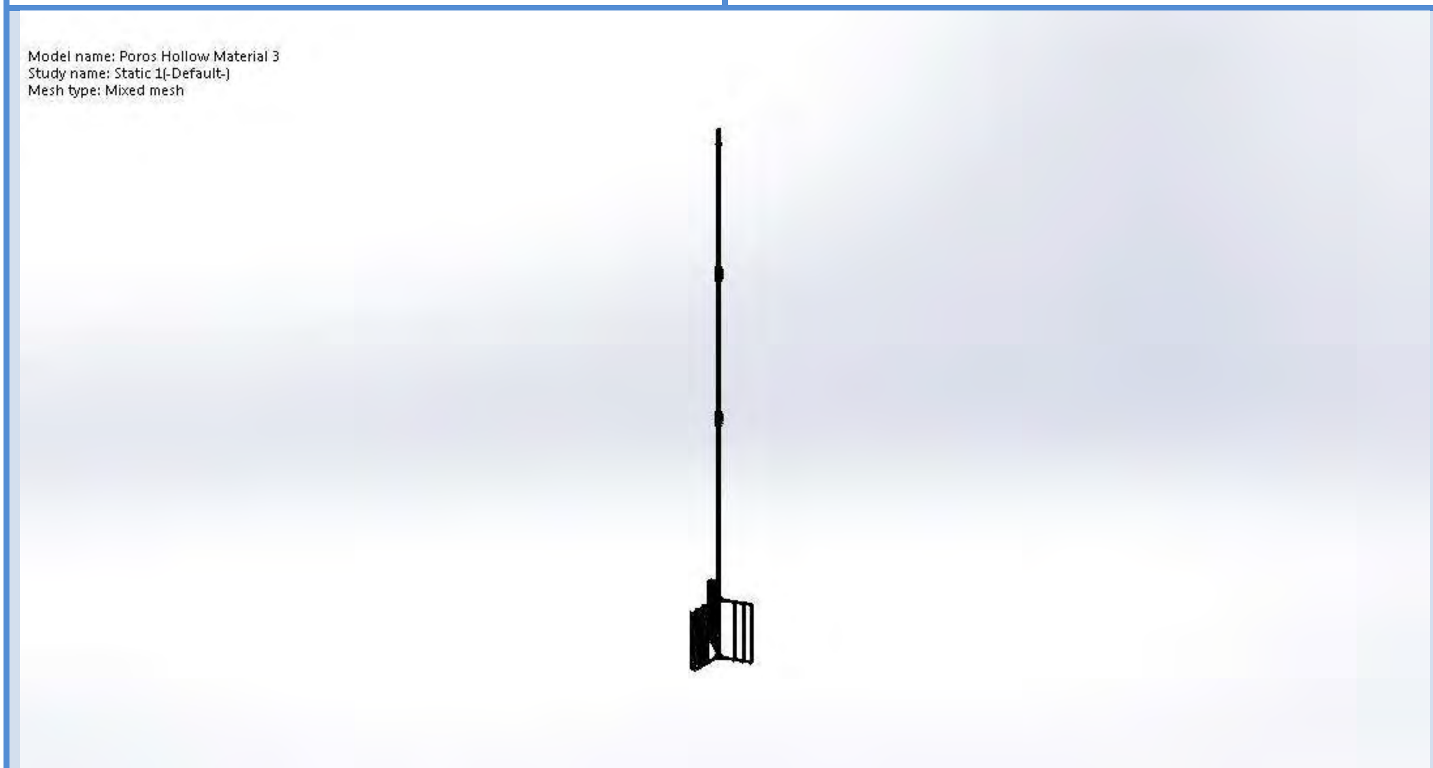
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Incompatible mesh

Mesh Information

Mesh type	Mixed Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Jacobian check for shell	On
Element Size	20.1415 mm
Tolerance	1.00707 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh Information - Details

Total Nodes	74465
Total Elements	36513
Time to complete mesh(hh;mm;ss):	00:02:54
Computer name:	TK02-PC



Sensor Details
No Data

Resultant Forces

Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	4158.9	1497.84	2367.96	5014.69

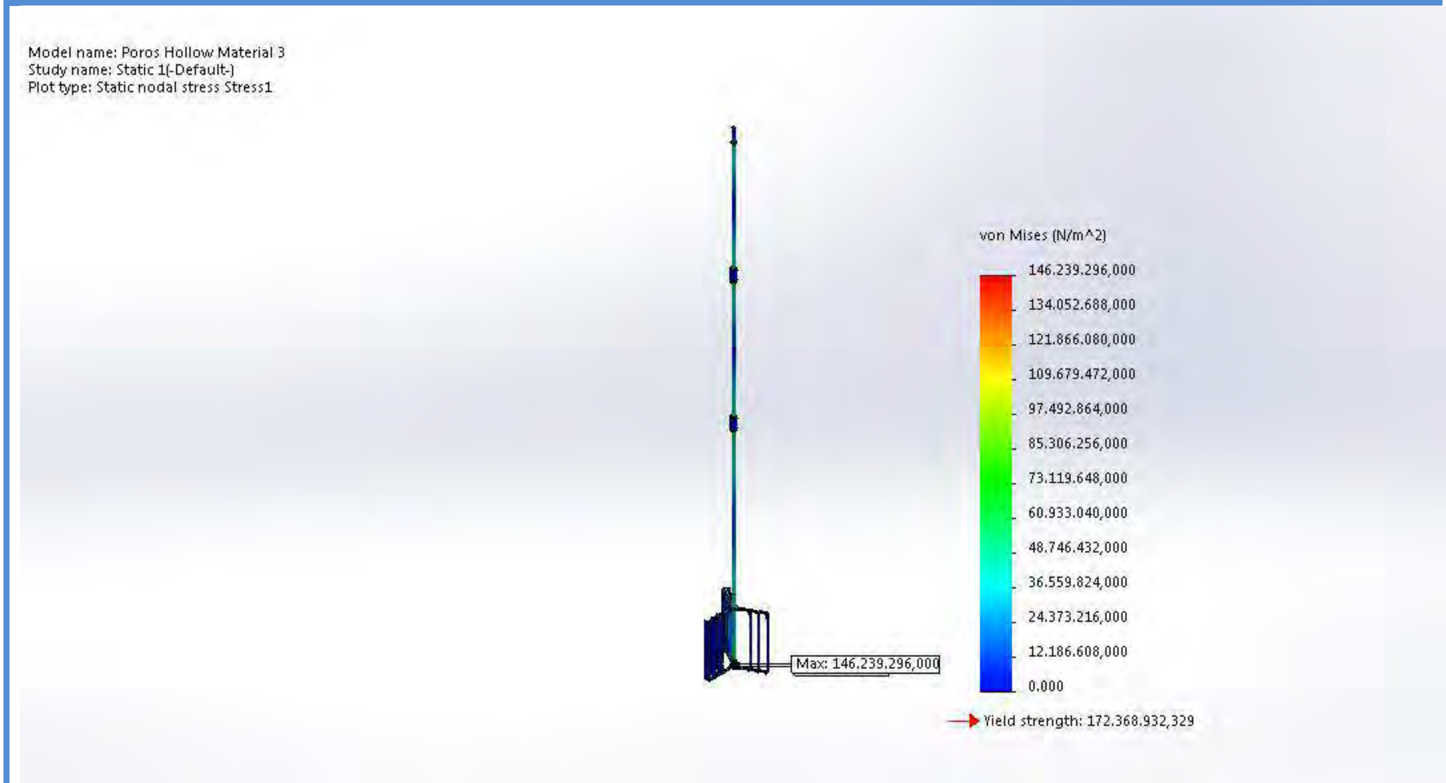
Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	1.77747e-008	-1.01377e-008	-5.28338e-008	5.66579e-008

Beams
No Data

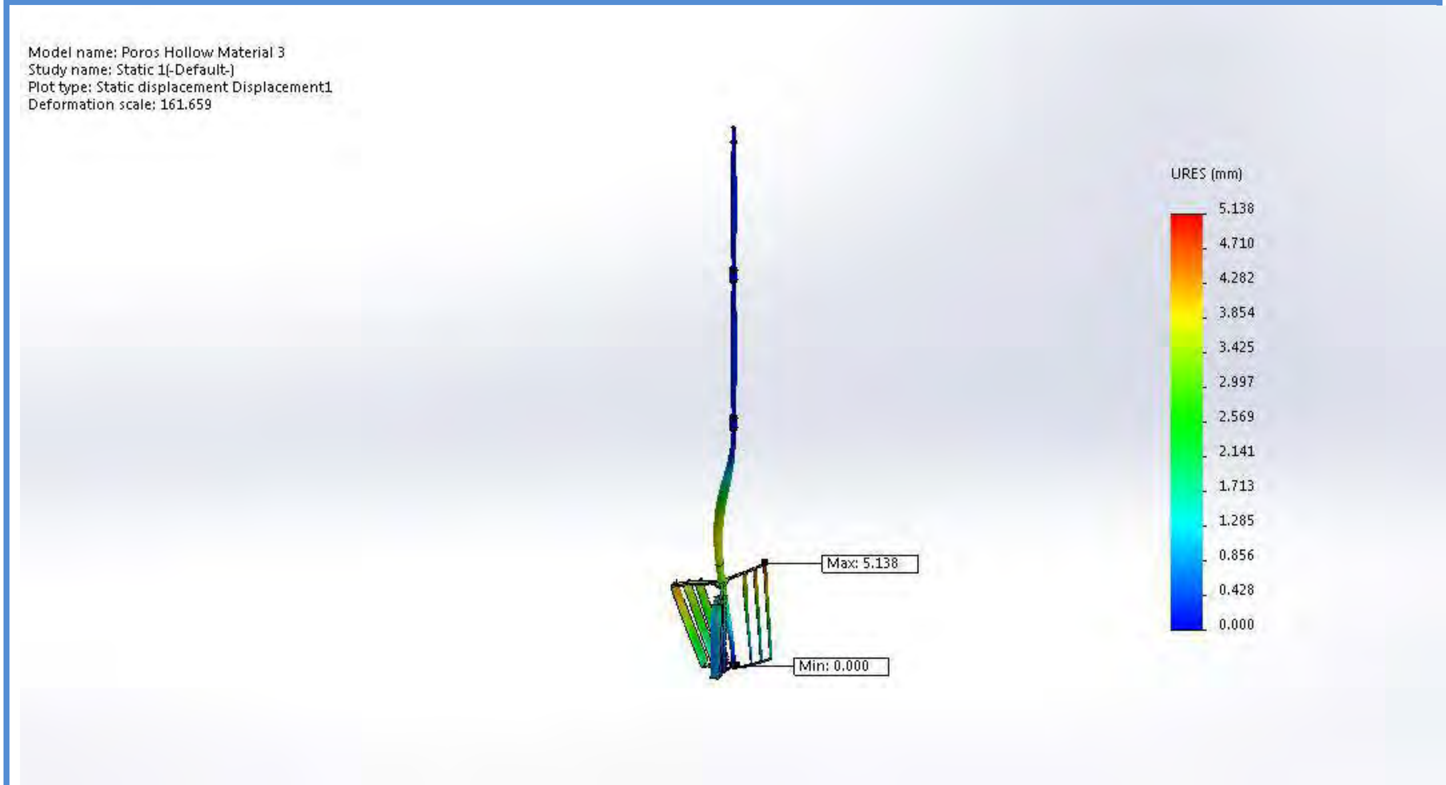
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0 N/m^2 Node: 61935	1.46239e+008 N/m^2 Node: 12693



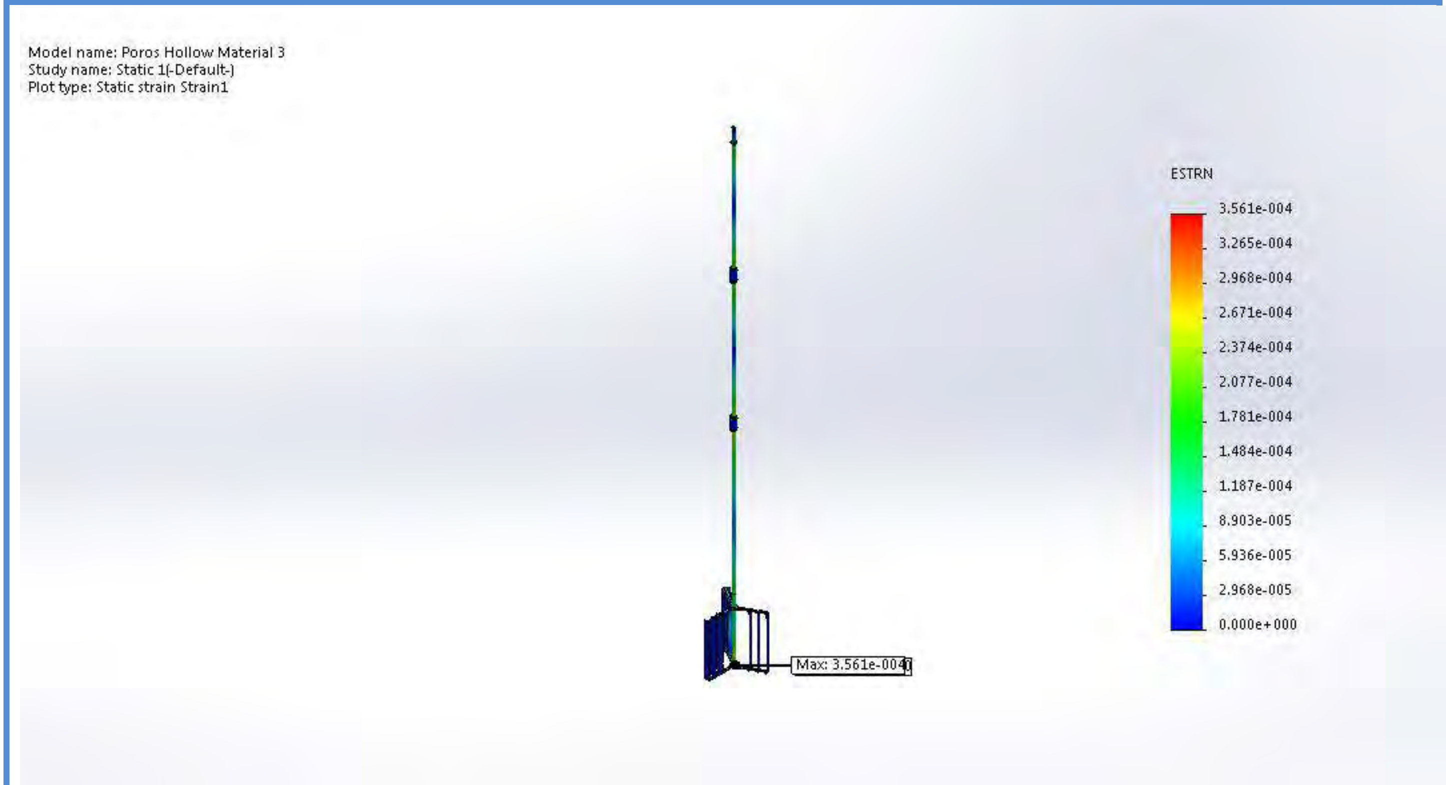
Poros Hollow Material 3-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 61935	5.13822 mm Node: 4868



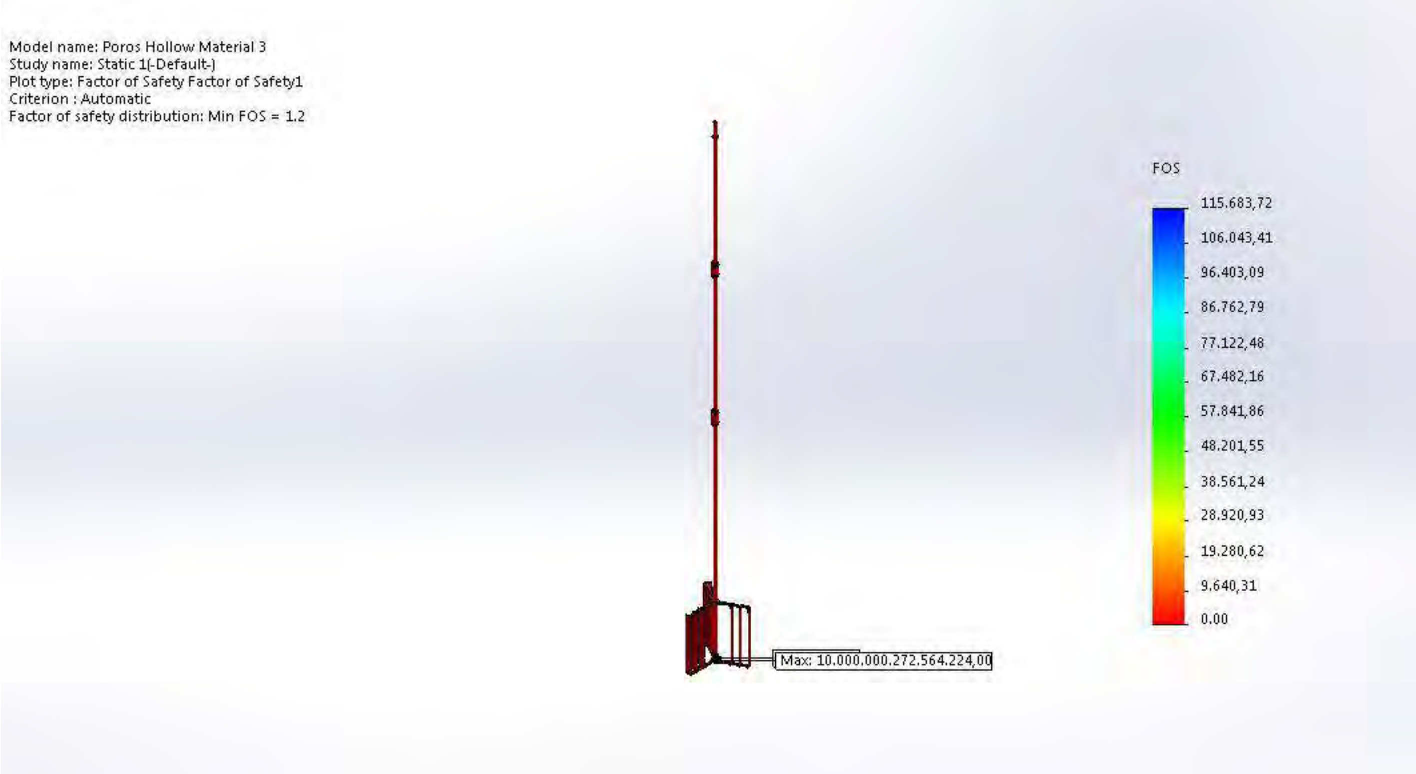
Poros Hollow Material 3-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0 Element: 30505	0.000356134 Element: 15110



Poros Hollow Material 3-Static 1-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Automatic	1.17868 Node: 12693	1e+016 Node: 61935



Poros Hollow Material 3-Static 1-Factor of Safety-Factor of Safety1

Conclusion

ATTACHMENT 11

Simulation Report of Solid Shaft Material 3

Simulation of Solid Shaft - Material 3 (Stainless Steel AISI 316)

Date: 28 Juli 2016
Designer: Solidworks
Study name: Static 1
Analysis type: Static

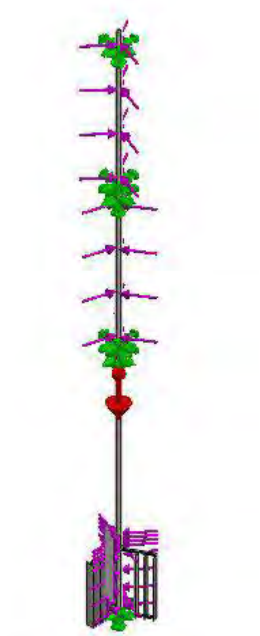
Table of Contents

Description

No Data

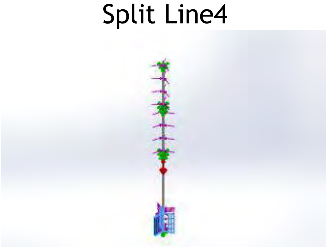
Assumptions

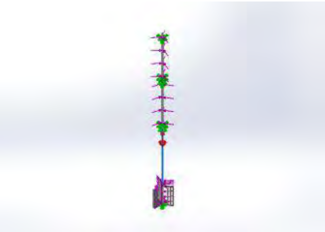
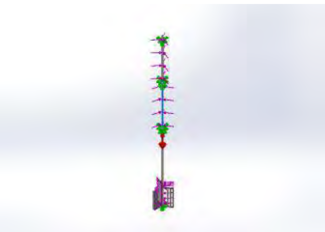
Model Information



Model name: Poros Pejal Material 3
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Split Line4 	Solid Body	**Mass:94.3534 kg** **Volume:0.0117894 m^3** **Density:8003.23 kg/m^3** **Weight:924.663 N**	**D:\Dhaifina Suci Soraya\Poros Hollow\NACA 0018.sldprt** Jul 27 23:24:05 2016

Boss-Extrude1 	Solid Body	**Mass:36.3757 kg Volume:0.00454696 m^3 Density:8000 kg/m^3 Weight:356.482 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\poros 1.SLDPRT** Jun 29 16:17:56 2016
Boss-Extrude1 	Solid Body	**Mass:31.4159 kg Volume:0.00392699 m^3 Density:8000 kg/m^3 Weight:307.876 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\poros 2.SLDPRT** Jun 29 16:17:56 2016
Body-Move/Copy1	Solid Body	**Mass:31.4159 kg Volume:0.00392699 m^3 Density:8000 kg/m^3 Weight:307.876 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\poros 3.SLDPRT** Jun 29 16:17:57 2016
Revolve1 	Solid Body	**Mass:4.01416 kg Volume:0.00050177 m^3 Density:8000 kg/m^3 Weight:39.3388 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016
Revolve1 	Solid Body	**Mass:4.01416 kg Volume:0.00050177 m^3 Density:8000 kg/m^3 Weight:39.3388 N**	**D:\Dhaifina Suci Soraya\Poros Pejal\Solid\soupling.SLDPRT** Jun 21 15:07:01 2016

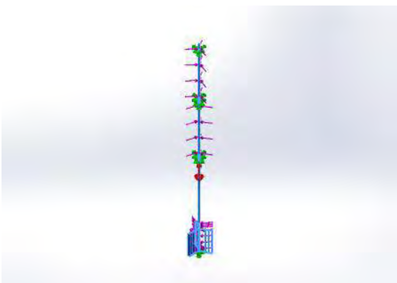
Study Properties

Study name	Static 1
Analysis type	Static
Mesh type	Mixed Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SolidWorks document (D:\Dhaifina Suci Soraya\Poros Pejal\Simulasi\Material 3 AISI 316 - Solid)

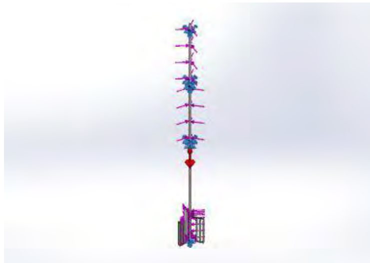
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

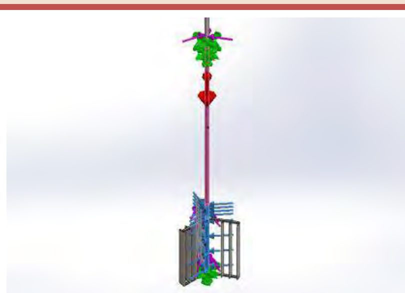
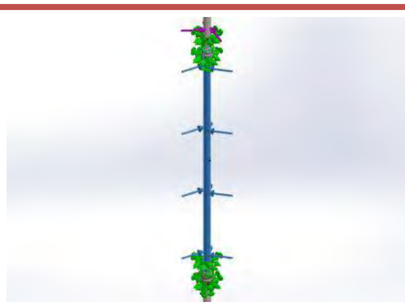
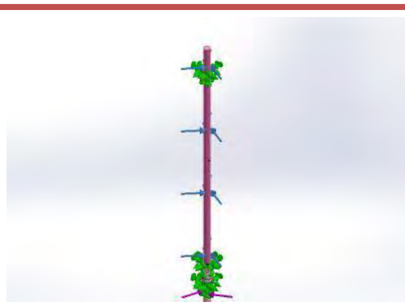
Model Reference	Properties	Components
	**Name:** AISI 316 Stainless Steel Sheet (SS) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Max von Mises Stress **Yield strength:** 1.72369e+008 N/m^2 **Tensile strength:** 5.8e+008 N/m^2 **Elastic modulus:** 1.93e+011 N/m^2 **Poisson's ratio:** 0.27 **Mass density:** 8000 kg/m^3 **Thermal expansion coefficient:** 1.6e-005 /Kelvin	SolidBody 1(Split Line4)(NACA 0018-1), SolidBody 1(Boss-Extrude1)(poros 1-1), SolidBody 1(Boss-Extrude1)(poros 2-1), SolidBody 1(Body-Move/Copy1)(poros 3-1), SolidBody 1(Revolve1)(soupling-1), SolidBody 1(Revolve1)(soupling-2), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-11), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-12), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-13), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-14), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-15), SolidBody 1(RollersDetailed)(thrust roller bearing_skf-16)
Curve Data:N/A		

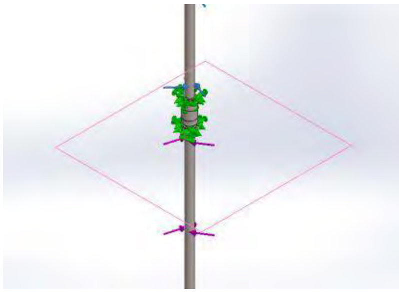
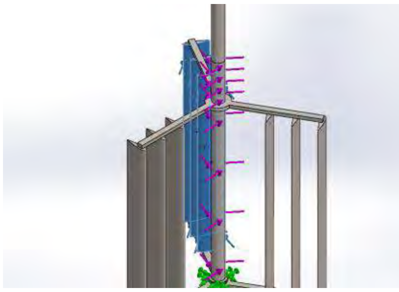
Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 12 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-308.784	-163.267	10.5091	349.449
Reaction Moment(N.m)	2.84275e-008	-1.52523e-008	-8.30107e-008	8.90591e-008

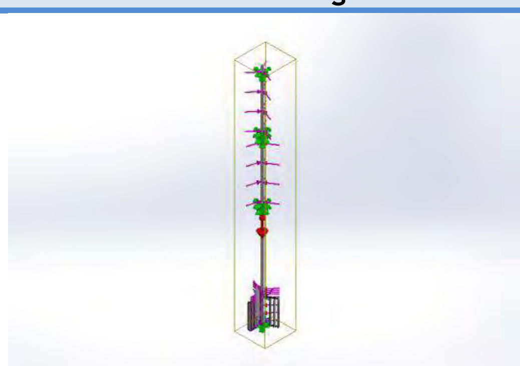
Load name	Load Image	Load Details
Torque-1		**Entities:** 2 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-2		**Entities:** 1 face(s) **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg
Torque-3		**Reference:** Face< 1 > **Type:** Apply torque **Value:** 1326 N.m **Phase Angle:** 0 **Units:** deg

Gravity-1		**Reference:** Top Plane **Values:** 0 0 -9.81 **Units:** SI
Force-1		**Entities:** 3 face(s) **Type:** Apply normal force **Value:** 1657.5 N **Phase Angle:** 0 **Units:** deg

Connector Definitions

No Data

Contact Information

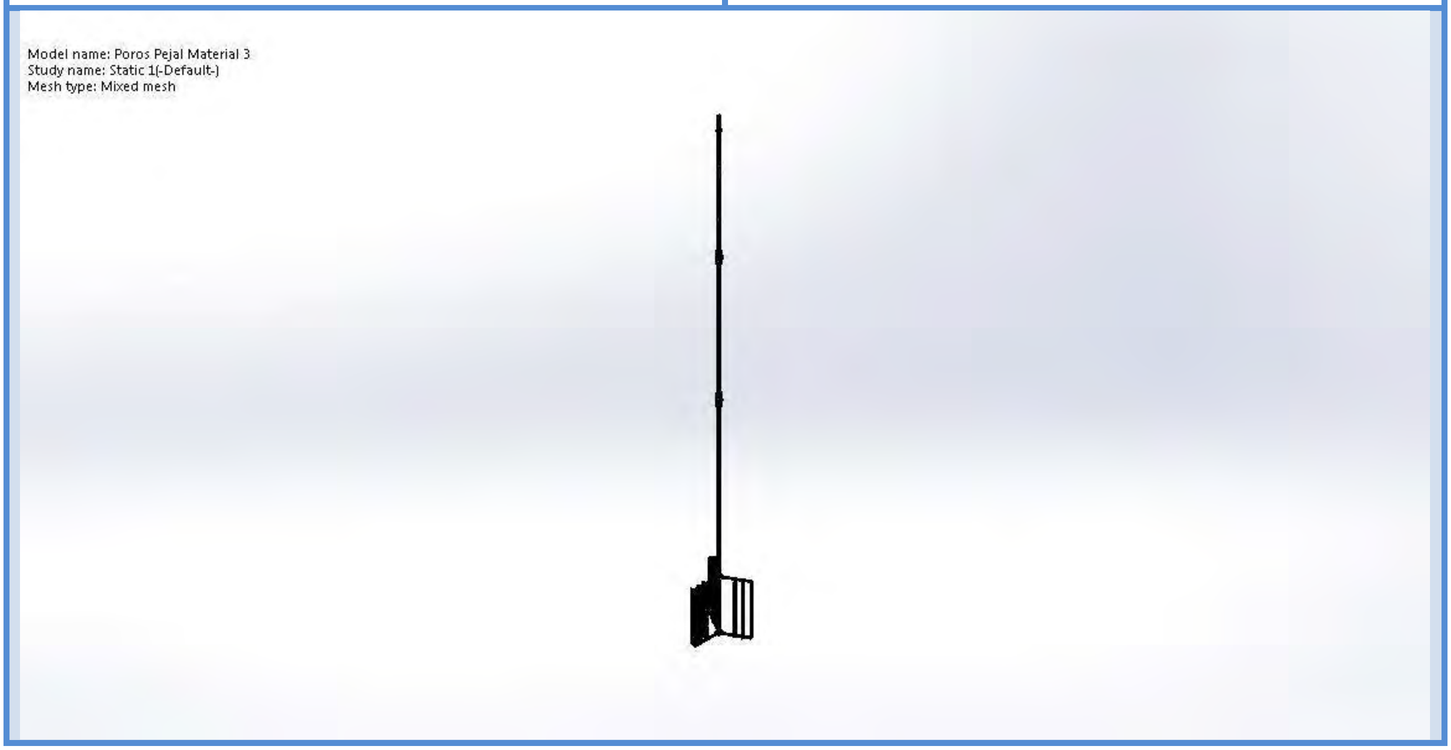
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Incompatible mesh

Mesh Information

Mesh type	Mixed Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Jacobian check for shell	On
Element Size	20.1415 mm
Tolerance	1.00707 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh Information - Details

Total Nodes	70365
Total Elements	35929
Time to complete mesh(hh;mm;ss):	00:03:05
Computer name:	TK02-PC



Sensor Details
No Data

Resultant Forces

Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	4158.87	1973.3	2367.96	5176.62

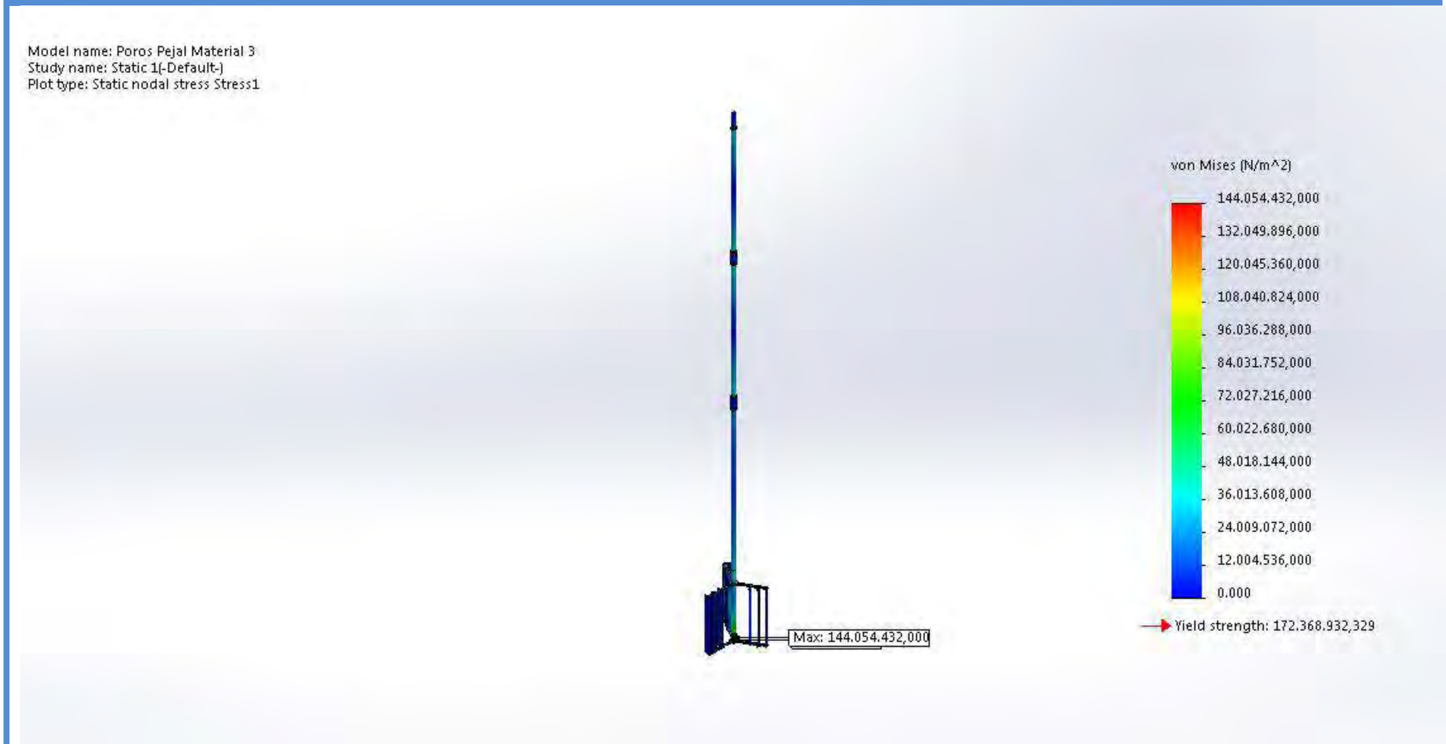
Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	3.23942e-008	-2.26389e-008	-2.9226e-008	4.91534e-008

Beams
No Data

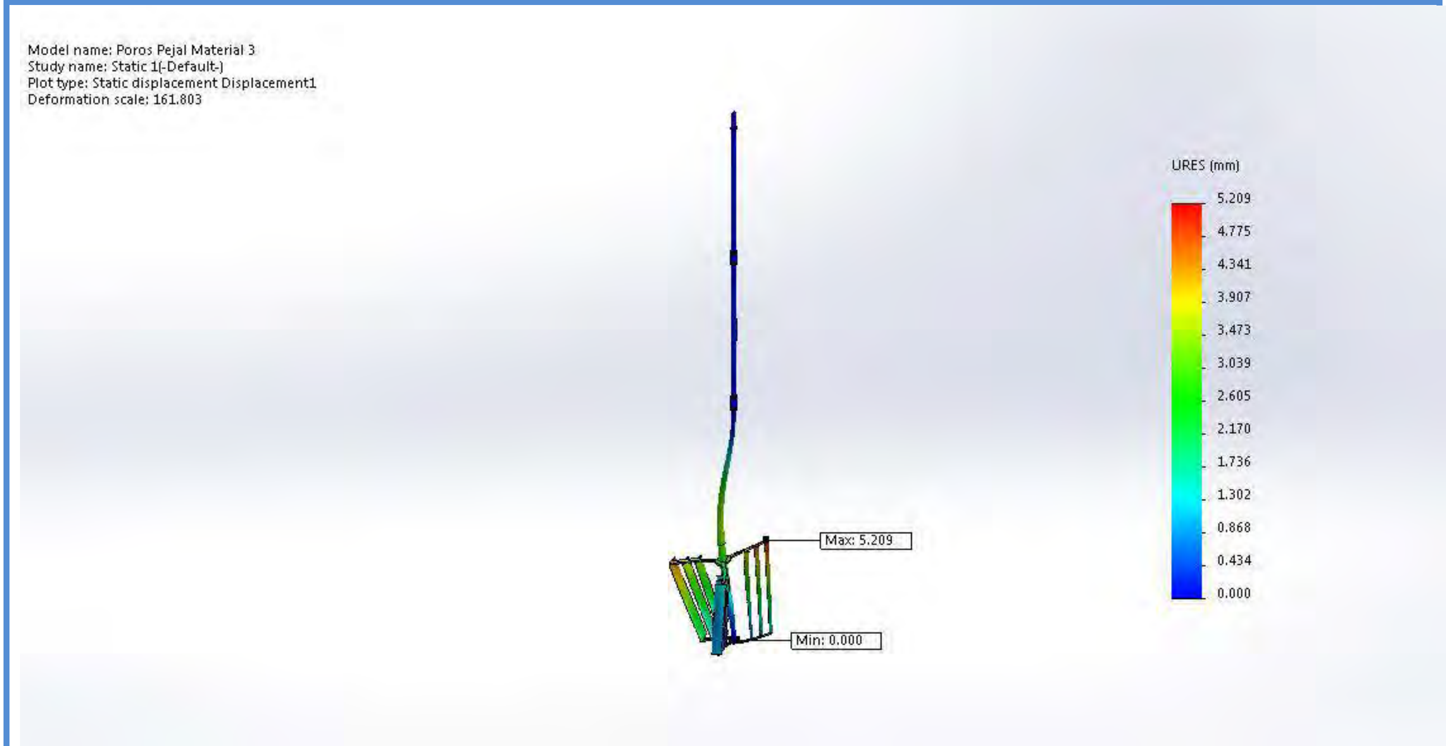
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0 N/m^2 Node: 57835	1.44054e+008 N/m^2 Node: 12693



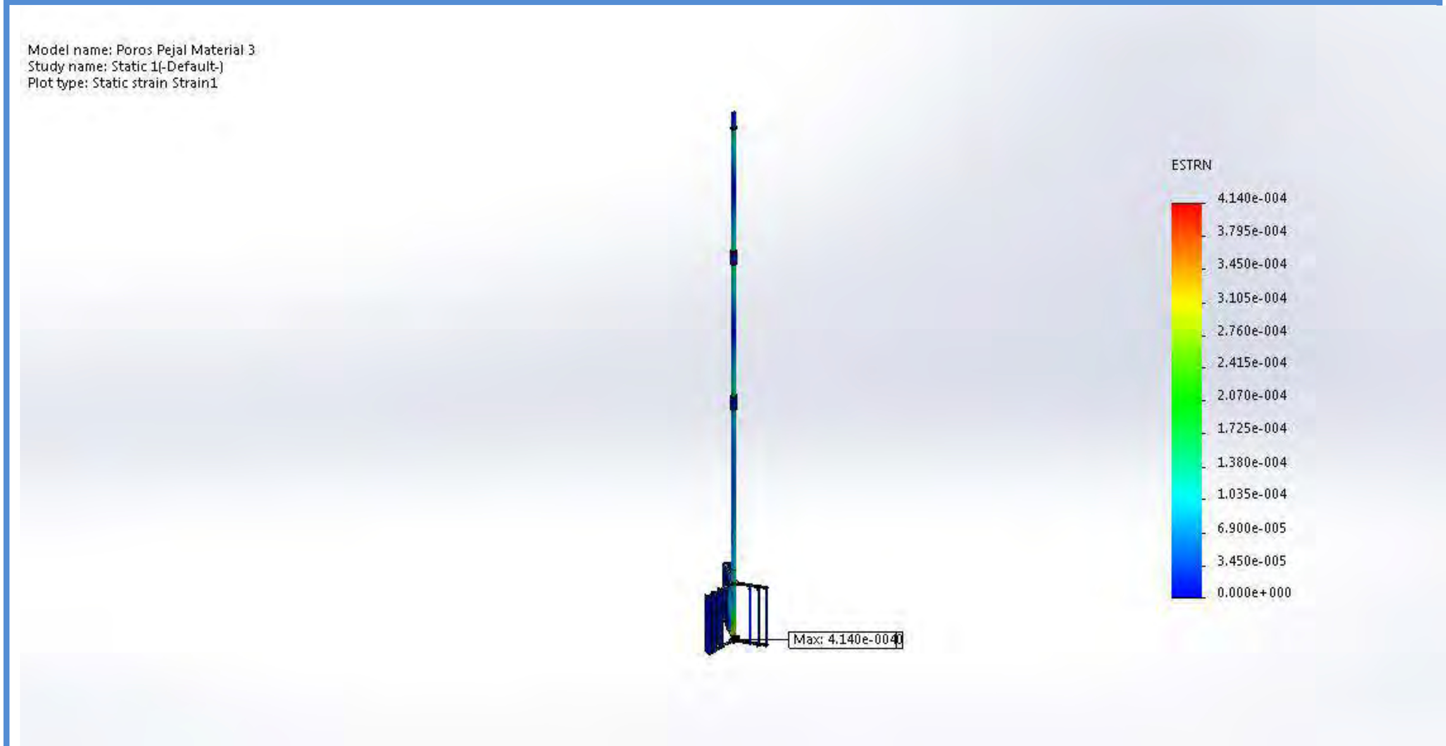
Poros Pejal Material 3-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 57835	5.20919 mm Node: 4868



Poros Pejal Material 3-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0 Element: 29921	0.000414003 Element: 15110



Poros Pejal Material 3-Static 1-Strain-Strain1

Name	Type	Min	Max
Factor of Safety1	Max von Mises Stress	1.19655 Node: 12693	1e+016 Node: 57835

Poros Pejal Material 3-Static 1-Factor of Safety-Factor of Safety1

Name	Type
Displacement1{1}	Deformed Shape

Poros Pejal Material 3-Static 1-Displacement-Displacement1{1}

Conclusion

CHAPTER 5
CONCLUSION

5.1 Conclusion

According data analysis, the discussion, and simulation result using finite element method, so it can be concluded that.

1) The recommendation for specification of vertical axis turbine shaft that capable for 5 kW capacity on ocean current power plant.

   - The VAT shaft is arranged by a series of three shafts having a length 3,3 m, 2 m and 2 m and made by round bar (solid shaft) with 0,05 m diameter.
   - The material recommended to use is High Tensile Steel AISI 4140/ASTM A434 (A29) Grade 4140 that have 1% chromium-molybdenum medium hardenability with ultimate tensile strength (s_u) of the material 850 – 1000 MPa and the yield strength (s_y) 665 Mpa.

2) The maximum stress of the VAT Shaft with round bar of High Tensile Steel AISI 4140 is 144,06 MPa, maximum strain 0,000385895, maximum displacement 4,81578 mm with deformation scale 175,333 and the vertical axis turbine shaft can be operated with factor of safety 4,5 based on simulation, and based manual calculation its sfaety factor is 4 Ans.

5.2 Recommendation

Recommendation that can be given by the author for further research are :

1) The result of this final project can be used as a reference to the detail design of mechanical transmission system such as gearbox system.
2) Calculation and simulation of vibration that occur need to be done, in order to get the efficiency and more accurate.

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BIOGRAPHY

The author was born in Lumajang, 21 February 1994, the author is the first child of three in her family and taken formal education at SDN Krian 04 Elementary School, SMPN 2 Jombang Junior High Cchool, and SMAN 1 Sidoarjo Senior High School. The author was graduated from SMAN 1 Sidoarjo in 2012, then continuing to bachelor degree and accepted at Institut Teknologi Sepuluh Nopember (ITS), Faculty of Marine Technology, Department of Marine Engineering in Double Degree Program with Hochschule Wismar Germany in 2012 and registered with student number 4212101007.

The author has keen of learning, not only in classes but also by doing job training, proved by job training at shipyard company, PT. PAL Indonesia (Persero) in 2014 and reliability engineering company, PT. Tiara Vibrasindo Pratama in 2015. The author take the Marine Manufacturing and Design (MMD) Laboratory for her concern to do research for this final project. During studying in Department of Marine Engineering, the author expect to be strong person, having good personality, friendly to everyone, and to helpful for the family, country, and community.

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